Identification of Variables Determining Intrahemispheric Interference Between Processing Demands

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for

Contracting Officer's Representative
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Basic Research Office
Michael Kaplan, Director

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This research note describes basic research aimed at understanding principles of brain hemisphere functioning which can be used to improve human performance. The research is most relevant for understanding performance based on visual information perceived by peripheral vision, and examines how intrahemispheric interference affects performance degradation when two task-related activities depend on the same hemisphere of the brain.

It was found that even in apparently simple tasks, small changes increasing or decreasing the difficulty of cognitive decision making are very powerful in determining how interactions within hemispheres will affect performance. When intrahemispheric interference occurred, changes in response requirements simplifying the decisional processes necessary to organize the response served to reduce interference. Effects of intrahemispheric interference may reduce performance based on stimuli in a particular location, or reduce it by one hand relative to the other. There are individual differences in the magnitude of intrahemispheric interference and its effects degrading performance as well.

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PREFACE

The research described in this report was conducted at the Georgia Tech Research Institute of the Georgia Institute of Technology under the technical supervision of Dr. Joanne Green. The research was performed in the Human Performance Branch of the Concepts Analysis Division of the Systems Engineering Laboratory. The Technical Representatives for the U.S. Army Research Institute were Dr. Robert M. Sasmor, Dr. Judith Orasanu, and Dr. Aaron Hyman.

The success of the research has depended heavily on the contributions of a number of individuals. Drs. Sasmor, Orasanu, and Hyman facilitated administration of the project and made useful conceptual contributions. The project has benefited from steadfast Georgia Tech management support provided by Mr. Robert P. Zimmer, Mr. William E. Sears, III, and Dr. Theodore J. Doll. Particularly important here was the decision to invest in improved laboratory facilities which allowed a more efficient allocation of fiscal resources in the contract. Major contributions to the performance of the experiments and data analysis were made by Mr. William Engelman, Mr. Peter DeNatale, and Mr. Larry Najjar. The hardware and software configurations used in the lab benefited significantly from contributions made by Mr. Michael Furman, Mr. Harold Engler, Mr. Philip D. West, Mr. Thomas Coonan, and Mr. Andrew H. Register.

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SECTION I
EXECUTIVE SUMMARY

This report describes basic research aimed at understanding principles of brain hemisphere functioning that can be applied to improving human performance. Although the brain hemispheres are similar in shape, each has specialized capabilities and unique resources. The manner in which each hemisphere functions is an important determinant of the efficiency with which certain types of stimuli can be processed and certain types of responses can be made. More refined understanding of principles of brain functioning can improve prediction of the impact of specific stimulus-response configurations being considered in training design, human-machine interface design, or personnel selection. The ultimate goal of the research is to contribute to improving performance in the stressful, information-overload environments frequently confronted by military operators. In such conditions, it is critical to optimize as many factors as possible, including those influencing the efficiency of brain functioning.

The research is most relevant to understanding performance which must be based on visual information which is perceived to the left or right of where the operator's vision is focused, i.e., information which is perceived in peripheral vision. Such conditions are often faced by pilots, who must detect visual signals in the cockpit while focusing on events outside of the cockpit, or by operators of other complex systems, who must focus on a particular display, but also detect critical signals on other displays located to the left or right. In such conditions, because of the way the nervous system is organized, the visual signals appearing lateral to the point of visual fixation are initially received by only one of the two brain hemispheres. The efficiency with which that hemisphere can process the received information will therefore affect the overall quality of performance.

The research also has great relevance for predicting performance in tasks in which a critical response involves finger movements by one hand (e.g., a button-pressing response). Such responses depend heavily on the functioning of one hemisphere. Here, again, the efficiency of that hemisphere for

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directing the response can affect the speed of performance.

The focus of the research was on understanding factors governing the magnitude of intrahemispheric interference between different processing activities associated with the same brain hemisphere. Such interference reduces the efficiency of that hemisphere and, hence, of performance. Of particular interest was the influence upon performance of interactions between two critical aspects of information processing: stimulus processing required to recognize and make decisions regarding stimuli, and response processing required to organize and execute motor responses.

These factors were studied in a series of seventeen experiments conducted at Georgia Tech over a three-and-one-half year period. The conclusions of the research are as follows:

1. Speed of performance can be significantly increased or decreased by the nature of interactions between stimulus processing and response processing activities associated with the same hemisphere. Whether performance is degraded or facilitated appears to be related to characteristics of the task which determine the general level of central processing difficulty, and to the dependence of stimulus processing upon a specific brain hemisphere.

2. In tasks vulnerable to the degrading effects of intrahemispheric interference, reduction in response processing difficulty decreases such effects, and results in faster response time.

3. Effects of intrahemispheric interference upon performance are manifested in a variety of ways: a. in terms of slowing performance based on stimuli in a particular location, i.e., either those to the left or right of the point of visual focus, or b. in terms of slowing performance by one hand, relative to the other. The latter effect can result in left hand response being faster than right-hand response, for right-handed subjects performing certain tasks.

4. There are individual differences in the magnitude of intra-hemispheric interference, and in the manner in which such effects degrade performance. Identification of measurable characteristics associated with these individual differences can be used to better tailor system and training design for particular individuals.

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Given the basic nature of the research, the applied implications require further validation in conditions closer to those faced by military operators. However, the preliminary implications can be broadly stated as follows:

1. Lateral locations for stimuli and types of responses which have been determined to be optimal for one task should not be assumed to be optimal for other tasks. The nature of the task can cause variations in brain hemisphere-related effects which result in differences between tasks in the nature of optimal stimulus and response characteristics.

2. In tasks requiring discrimination between stimuli, intrahemispheric interference may be minimized and response time speeded if operators are required to make motor responses for only a subset (ideally, only one) of the stimuli. This is because reduction in the need to choose between motor responses reduces interference.

3. If either the right or left hand can be used to control a response, preliminary testing should be done to determine if one hand responds more quickly for a given task. It should not be assumed that the right hand will be faster for right-handed individuals.

4. Since there are individual differences in the magnitude and nature of hemisphere-related effects upon performance, the precise level of performance of a given task by a given individual is difficult to predict. Additional research is necessary to identify measurable, individual characteristics predictive of the magnitude of such effects. At this time it is recommended that for highly critical tasks, preliminary screening be performed for each task to select individuals whose performance is optimal for that task.

SECTION II
BACKGROUND TO THE RESEARCH

A. Introduction

This report describes research examining certain principles of brain functioning and their impact on human performance. The report is organized as follows. The remainder of this section and Section III summarize information detailed in two earlier interim reports (First Interim Report, April, 1983; Second Interim Report, January, 1984). The remainder of this section briefly reviews the theoretical and empirical basis for the research, including the rationale and objectives of the selected approaches to examining the questions of interest. The practical importance of the research is also indicated. In Section III are summarized the results and conclusions of the first twelve studies. The reader is referred to the interim reports for greater detail.

The focus of this final report is on research conducted since the last interim report was written, and on integrative conclusions and recommendations. In Section IV are detailed the purpose, methods, and results of Experiments 13 through 17. In the later phases of the research, analysis of individual differences became of major interest. These preliminary analyses are described in Section V. Overall conclusions regarding the research are discussed in Section VI. These include conclusions regarding theoretical and applied implications of the research, as well as recommendations for future research.

B. The Context for the Research

When stimuli are perceived in a lateral visual field, their direct retinocortical projections are to the hemisphere contralateral to that visual field. As Figure 1 illustrates, stimuli occurring in the left visual field initially project to the right hemisphere and stimuli occurring in the right visual field initially project to the left hemisphere. Also, hand movements (particularly fine finger movements) are largely controlled by the hemisphere contralateral to the responding hand (Brinkman & Kuypers, 1972; Lawrence & Kuypers, 1968; Myers, 1962). Thus, by manipulating visual field of stimulus presentation and response control, one can control both the hemisphere which

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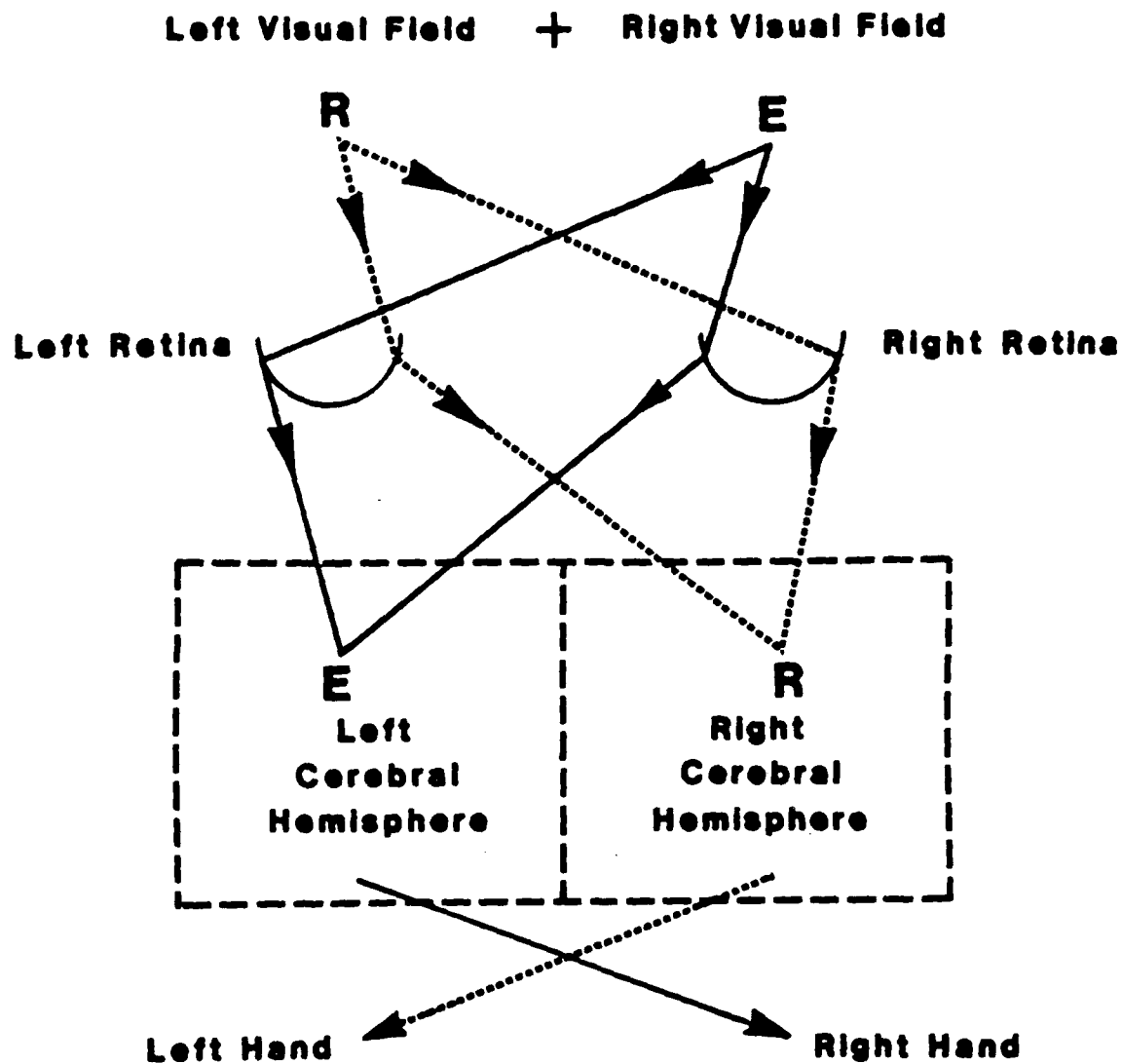
Figure 1. A Schematic Diagram of Neural Connections to the Cerebral Hemispheres.

initially receives stimulus information and the hemisphere which controls the response.

Because of these contralateral connections, performance based on lateralized visual stimuli is affected by the processing capabilities of the hemisphere to which they project. These effects are manifest in two major ways. First, specialization of each hemisphere for certain types of process-ing can cause performance to be better when stimuli are directly projected to the hemisphere specialized for the type of processing required for task performance. The left hemisphere has been described as being better at tasks requiring verbal/serial processing, while the right hemisphere has been described as being better at tasks requiring visuospatial/wholistic processing. Although there has been considerable recent discussion of the dimensions discriminating the hemispheres' specialized capabilities (e.g., see Bradshaw & Nettleton, 1981; Sergent, 1982), a wealth of converging evidence supports the notion that specialized hemispheric capabilities can affect the quality of performance.

Second, a variety of evidence suggests that independent processing resources associated with each hemisphere influence the capability of each hemisphere to process stimuli projecting to it. Within the past few years, several major conceptual papers (Friedman & Polson, 1981; Friedman, Polson, Dafoe, & Gaskill, 1982; Wickens, 1980) have argued that the two hemispheres, although highly communicative with one another, may have separable, indepen-dent, processing resources. This suggests that performance will be better if task demands are divided between the hemispheres, thus utilizing the resources of both hemispheres. Conversely, there may be intrahemispheric interference between processing demands associated with the same hemisphere because only the limited resources of one hemisphere are being tapped. Such interference may reduce the quality of performance.

A large number of empirical studies support the notions that there are hemisphere-associated processing resources, and that interference may occur between task demands imposed on a single hemisphere. The studies fall into a variety of categories: a) those demonstrating interference between stimulus processing activities associated with one hemisphere (Dimond, 1972; Moscovitch & Klein, 1980), b) those demonstrating interference between stimulus process-ing and memory activities (Geffen, Bradshaw & Nettleton, 1973; Hellige, Cox &

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Litvac, 1979), c) those demonstrating interference between response activities (Hicks, 1975) and d) those demonstrating interference between stimulus processing and response-associated activities within one hemisphere (Green, 1984; Gross, 1972).

The results of these studies all point to the conclusion that there is sometimes interference between processing activities occurring within one hemisphere. The fact that performance is facilitated when these processing demands are divided between the hemispheres suggests that each hemisphere has to some extent its own processing resources, which cannot be allocated to the other hemisphere. This supports the conceptualization of the two hemispheres as separable information processing systems, somewhat independent of one another, each having a certain degree of non-sharable processing resources. This is consistent with dual channel, rather than single channel, models of the brain.

The implication of this view for visual task design is that performance may sometimes be facilitated if the task design encourages a division of processing activities between the hemispheres, thus minimizing intrahemispheric interference. In particular, for a given response, reaction time to lateral stimuli may be faster if stimuli are projected to the hemisphere not controlling the response. This implies that for manual responses involving heavily unilateral hemispheric control (e.g., finger movements), performance may be optimal when the stimulus appears in the visual field contralateral to the body side of hand origin.

The major motivation for the present research was the observation that despite both theoretical and empirical justification for such a design principle, there are also results indicating that it is not always appropriate. This is because there exist both theoretical and empirical bases for arguing that performance is sometimes optimal when the stimulus appears in the visual field ipsilateral to the body side of hand origin. The simplest basis for suggesting this is related to the concept of stimulus-response spatial compatibility (Fitts & Seeger, 1953; Wallace, 1971). A variety of studies have indicated that when a manual response is laterally located, right hand responses are faster for right visual field stimuli and left hand responses for left visual field stimuli. Such effects have most frequently been studied in simple tasks (e.g., stimulus detection, simple or choice

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stimulus recognition), and occur in auditory, visual, and sensory modalities (Simon, Sly, & Vilapakkam, 1981). It has been argued that there is an advantage for conditions in which stimulus and response are ipsilateral because there is a greater compatibility in their internal codes due to spatial similarity.

Such effects are potentially problematic for visual studies of the brain hemispheres involving laterally-appearing stimuli. Because the lateral spatial location of the hand (rather than hand identity) has been identified as a critical factor determining stimulus-response compatibility effects, it has been recommended that manual responses be centrally located in studies of brain hemisphere capabilities (Young, 1982). This was the approach used in the present research.

A second basis for qualifying the principle of contralateral organization of stimulus and response are certain hemisphere-related studies. A number of researchers have found that reaction time is faster when stimuli are projected to the hemisphere controlling the response (Berlucchi, Heron, Hyman, Rizzolati, & Umilta, 1971; Bradshaw & Perriment, 1970). These studies have generally involved tasks with relatively simple processing demands (e.g., stimulus detection), and have been interpreted as demonstrating the advantage of omitting interhemispheric transmission time.

An advantage for performance dependent on processing activities within the same hemisphere would also be predicted in terms of activation effects (Kinsbourne, 1970). Non-hemisphere-related studies have reported facilitatory "priming" effects of earlier semantic processing on subsequent semantic processing (Posner, 1978). These effects can be easily interpreted as reflecting the facilitatory effects of activating particular brain areas. The effects imply that activation of a brain area (e.g., hemisphere) by one processing activity can benefit subsequent activities dependent on that area.

In summary, although there is considerable justification for considering effects of intrahemispheric interference in designing tasks, there is a need to better understand the conditions in which such effects predominate in determining the quality of performance. The present research was designed to address that need.

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C. Rationale and Objectives of Theoretical Approach

The major focus of investigation was how the level of task processing demands, particularly in terms of difficulty, affected the occurrence and magnitude of intrahemispheric interference. The importance of this factor was originally suggested by comparisons of studies in which intrahemispheric interference did or did not appear. In general, studies demonstrating intrahemispheric interference involve relatively more demanding stimulus and/or response processing requirements. For example, the studies by Berlucchi, et al. (1971) and Bradshaw and Perriment (1970) both involve simple stimulus detection. In contrast, the studies by Green (1984) and Gross (1972) both involve classification of pairs of very briefly presented, relatively more complex, stimuli. Although the concept and determinants of processing demand/load are complex and as yet, ill-defined (see Moray, 1979; Kahneman, 1973), comparisons such as these suggest that variations in processing demands may be important in determining when intrahemispheric interference occurs.

The specific objectives of the present research were therefore as follows:

a. To examine how variations in the level of processing demands affected the level of intrahemispheric interference.

b. To examine the generality of the effects of intrahemispheric interference across tasks.

The research has focused primarily on effects of variations in stimulus processing demands and response processing demands. More indirect evidence has also allowed some inferences concerning the effects of central processing demands. During the course of the research, the importance of individual differences became apparent. This factor was therefore given some attention in the analysis of the more recent studies.

D. Methodological Approach

The program has involved a series of experiments systematically varying stimulus processing and response processing requirements. A major rationale guiding the choice and sequence of the experiments is the necessity at this stage in the research for very careful and systematic manipulation of the potentially important variables. For the most part, each experiment is distinctly different from its predecessor on only one parameter. This produces a

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relatively conservative sequence of experiments. This conservatism is, however, well justified in view of the present confusion found in literature reporting reaction time studies of hemispheric processing in normal individuals. Large discrepancies exist between the outcomes of apparently similar experiments. Much of this confusion can be largely attributed to small, unnoticed, but probably significant differences between apparently similar experiments.

The research program was designed to avoid this problem by including a sequence of experiments having the same basic design, with each differing in a critical, hypothetically important feature. This careful control of variables results in conservative research, but minimizes the possibility of confounding by variables not recognized as important. The features which are varied are those which the earlier discussion identified as being potentially critical for the occurrence of intrahemispheric interference.

Each experiment was characterized by brief presentation of stimuli in the left and right visual fields, thus initially projecting information to the right or left hemisphere, respectively. Each test session required keypress responses by the fingers of one hand, allowing inference that the hemisphere contralateral to the hand directed response movement. In the majority of studies, the occurrence of intrahemispheric interference was inferred when there was a responding hand by visual field interaction such that performance (measured primarily in terms of reaction time) was worse when the stimulus was projected to the hemisphere controlling the response, that is, when there was a disadvantage for stimuli ipsilateral to the responding hand.[1]

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[1] It is important to note that the existence of a significant interaction of the type described is probably best interpreted as evidence of interference differentially affecting the two hemispheres, that is, affecting one hemisphere more than the other in a given set of conditions. The absence of such an interaction may mean that intrahemispheric interference is eliminated but it could also mean that the two hemispheres are being equally affected. The present approach can indicate when differential interference is eliminated but not when all interference is eliminated.

The general approach to data analysis was to perform an overall analysis of variance, with particular interest in the significance of the responding hand by visual field interaction. For purpose of finer analysis, t-tests were done on what will be called "interaction scores," computed for specific stimulus types, e.g., for match pairs in the letter-matching tasks. The interaction score is computed as shown in Table 1. In general, the more positive the interaction score, the greater is the level of intrahemispheric interference that is inferred.

E. Practical Importance of the Research

This research has focused on investigation of some of the basic parameters and processes affecting differential information processing by the two cerebral hemispheres. As is clear from the completed research and from review of existing literature, understanding of hemispheric functioning is becoming more complete. There is, however, need for continued basic and applied research to clarify the implications for addressing real-life problems.

It is, however, possible at this time to identify a variety of conditions in which better knowledge of hemispheric functioning might facilitate human performance. Differential capabilities of the hemispheres are of special relevance to tasks in which one hemisphere either initially receives critical stimulus information and/or controls response. Such tasks include those in which performance must be based on detection or recognition of visual information appearing lateral to the point of visual fixation. In such conditions the lateral stimulus initially projects to the contralateral hemisphere. Tasks in which response is made by one limb (e.g., the right hand) are also affected by the capabilities of the contralateral, controlling hemisphere to direct the response.

One example of a situation in which differential hemispheric capabilities and the effects of intrahemispheric interference are relevant is the performance required of an Army pilot controlling an aircraft, such as a plane or helicopter. Such a pilot can base performance on a wide array of visual information including that viewed external to the cockpit and that appearing on displays within the cockpit. Cockpit displays include aircraft attitude indicators (e.g., pitch, roll), the gunsight display, system warning lights,

TABLE 1

Computation of Interaction Score.

Visual Field →		Left	Right
Responding Hand ↓			
	Left	a	b
	Right	d	c

Interaction Score = (a − b) + (c − d), where a, b, c, d are reaction time.

and radar warning-receiver displays. Since in normal conditions of flight the pilot trys to monitor simultaneously as many of these displays as is possible, the best viewing strategy is to look mainly straight ahead, allowing peripheral vision to catch information from displays to the left or right. In fact, many of the laterally placed displays are designed so that the appearance of highly significant information on them provides cues (such as brightness or color changes) that are relatively perceptible in peripheral vision. The "straight-ahead" viewing strategy means that information appearing in lateral displays is initially received by either the left or right cerebral hemisphere.

In addition to monitoring a large amount of visual information, the pilot must translate what is perceived into appropriate responses for controlling or defending the aircraft. These include manipulation of the control stick to vary roll and pitch, manipulation of the throttle to control speed, and a variety of button-pressing responses required to trim aircraft attitude, control information presentation on the radar warning-receiver display, release weapons, and perform other critical functions. Whenever these responses involve fine finger movements, or possibly fine manual control of any type, the hemisphere contralateral to the responding limb initiates the response.

Even in non-battle flight, the wide array of visual information and possible responses creates conditions of information overload in which the pilot may miss critical information. In battle conditions, efficient performance becomes even more important, even as the amount of critical information and stress on the individual increase.

Rapid correct response to visual information is equally important in the behavior of radar operators, who deal with an equally challenging, but different information processing task. Radar operators must view visual displays over long periods of time to detect critical signals which sometimes appear in a background of other non-critical signals. The critical signals may be difficult to detect or may be different from the noise signals only in subtle features. Since the entire display cannot be viewed foveally, many of the signals are initially received by only one of the cerebral hemispheres, making hemispheric processing efficiency of critical importance for signal recognition.

In the tasks performed by pilots or by radar operators, the design of the visual displays and of the required response modes to facilitate rapid information processing becomes extremely critical. The greater the importance of rapid, efficient, information processing, the more significant are design features which have even small benefits for performance.

Basic research such as that performed in the completed program has potential for contributing to more effective task design. The research aims at identifying some of the conditions and variables associated with intrahemispheric interference between processing activities originating within the same hemisphere. Identification of the variables controlling intrahemispheric interference and of the range of conditions in which it occurs will suggest the extent to which such interference may be slowing performance of visual tasks performed by Army personnel. Identification of the conditions in which a significant amount of intrahemispheric interference occurs will allow task design to account for these effects. For example, for tasks in which significant intrahemispheric interference occurs, the visual information displays could be designed so that stimuli initially project to the hemisphere not controlling the response. If a modification of display design were not possible, an alternative would be to change the response so that it was controlled by the hemisphere not receiving the stimuli.

SECTION III

SUMMARY OF EXPERIMENTS 1 THROUGH 12

A. Introduction

The purposes, methods, results, and discussion of Experiments 1 through 12 have been described in detail in two interim reports dated April, 1983 and January, 1984. The purpose of the present section is to review briefly these experiments in order to provide context for the subsequent experiments detailed in following sections of this report.

Table 2 summarizes the conditions and purpose of each experiment. For purpose of later discussion, it is important to note that what will be called Response Assignment 1 was used in all of the two-choice stimulus matching experiments with the exception of Experiment 12. Response Assignment 1 requires subjects to use the index finger to indicate match and the middle finger to indicate mismatch. In Experiments 1 through 12 the response was also made with the responding hand in a central location, with the fingers perpendicular to the stimulus display.

Figure 2 is a diagramatic illustration of the most crucial results for the present purposes, namely the responding hand by visual field interaction that is used to evidence intrahemispheric interference when present in Experiments 1 through 11. The nature of this interaction is such that response is slower for stimuli appearing in the visual field contralateral (rather than ipsilateral) to the responding hand. In other words, response is slower when stimuli project to the hemisphere controlling the finger keypress response. It was hypothesized that interference might occur as a function of degree of processing demand. Experiments 1 through 11 were initial attempts to investigate this hypothesis.

B. Research Findings

Experiments 1 through 3 were initial experiments examining factors determining intrahemispheric interference. The experiments involved match-mismatch judgments of pairs of upper case letters.

TABLE 2

Summary of Conditions of Experiments 1 through 12.

Critical variables in each experiment are underlined.

Experiment	Stimulus Presentation	Response	Primary Research Question
1	Matching of simultaneously presented and masked letter shapes	Within-hand choice	Do results of Green (1977) replicate in the Georgia Tech lab?
2	Matching of simultaneously presented but not masked letter shapes	Within-hand choice	Does intrahemispheric interference appear in a letter-shape matching task when stimulus processing demands are reduced?
3	Matching of simultaneously presented letter shapes	Go-no go	Does interference appear in a letter-shape matching task when response demands are reduced?
4	Matching of simultaneously presented face stimuli	Within-hand choice	Does interference appear in a face-matching task when response demands are relatively high?
5	Matching of sequentially presented face stimuli	Within-hand choice	Does interference appear in a face-matching task when stimulus processing demands are reduced but response demands are relatively high?

TABLE 2
(Continued)

Summary of Conditions of Experiments 1 through 12.

Critical variables in each experiment are underlined.

Experiment	Stimulus Presentation	Response	Primary Research Question
6	Matching of sequentially presented face stimuli	Go-no go	Does interference appear in a face-matching task when both stimulus processing and response demands are reduced?
7	Matching of simultaneously presented letter names	Within-hand choice	Does interference appear in a letter name matching task when stimulus processing and response demands are relatively high?
8	Matching of simultaneously presented letter names	Go-no go	Does interference appear in a letter name matching task when response demands are reduced?
9	Recognition of single letters	Within-hand choice	Does interference appear in a letter-recognition task?
10	Matching of simultaneously presented letter shapes; stimulus visual angle varied	Within-hand choice	Does interference magnitude increase when stimulus processing demands are increased?

TABLE 2
(Concluded)

Summary of Conditions of Experiments 1 through 12.

Critical variables in each experiment are underlined.

Experiment	Stimulus Presentation	Response	Primary Research Question
11	Matching of simultaneously presented letter-names; stimulus duration varied	Within-hand choice	Does interference magnitude increase when stimulus processing demands are increased?
12	Matching of simultaneously presented letter shapes	Within-hand choice; response assignment reversed from that used before	Does interference magnitude vary as a function of response assignment?
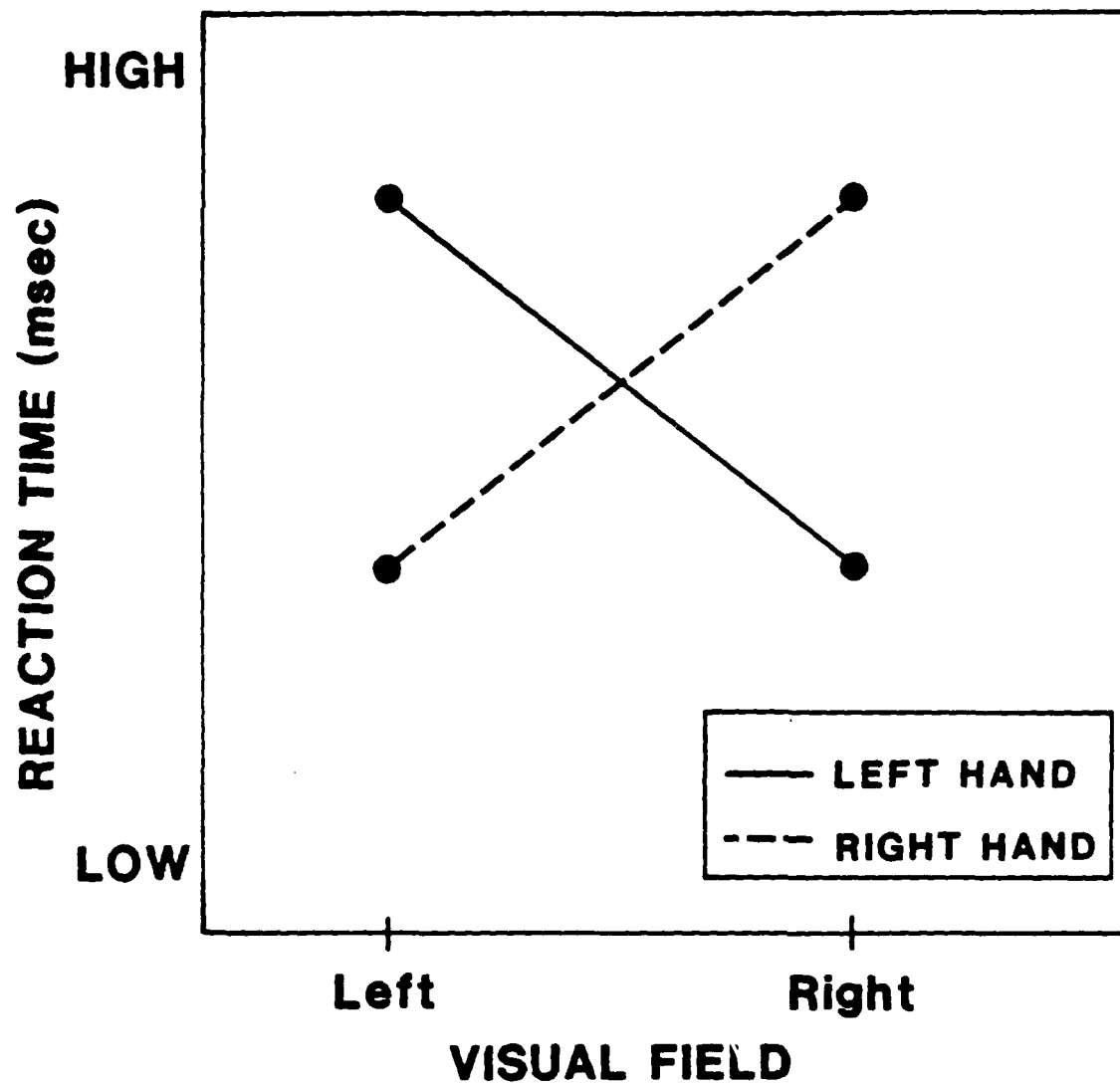
Figure 2. Data Pattern Consistent With Intrahemispheric Interference.

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Experiment 1 replicated the result of Green (1977), which has been used as primary evidence of intrahemispheric interference. This result is a responding hand by visual field interaction such that response is slower for stimuli appearing in the visual field contralateral (rather than ipsilateral) to the hand, i.e., for stimuli projecting to the hemisphere controlling the finger keypress response. It was hypothesized that interference might occur as a function of level of processing demands. Experiments 2 and 3 were initial attempts to manipulate such demands. In Experiment 2, stimulus processing demands were reduced by eliminating the stimulus mask that had appeared immediately following each stimulus pair in Experiment 1. It was hypothesized that mask elimination would allow subjects to access information in visual sensory store (Sperling, 1960), thus facilitating stimulus processing and perhaps reducing interference. In Experiment 3, response processing demands were reduced by requiring subjects to use a go-no go response to indicate their decision, rather than a choice response. The go-no go response is less complex in that it requires a given subject to keypress only in response to one of the two stimulus types, thus eliminating the necessity to choose between keys.

As can be seen in Figure 3, the results of Experiments 1 and 2 were highly similar indicating that reduction of stimulus processing demands, as operationalized by mask elimination, did not reduce intrahemispheric interference. In contrast, evidence of interference was clearly eliminated in Experiment 3, indicating that reduction in response processing demands was an important factor.

Experiments 4 through 11 examined the reliability of the stimulus and response processing effects across tasks. The major results are shown in Figure 4. The conclusions were as follows:

1. Intrahemispheric interference can affect a variety of stimulus matching tasks, including those involving letter-shape matching (e.g., Experiment 1) cartoon face matching (e.g., Experiment 4), and letter name matching (e.g., Experiment 7).

2. In all of the above tasks, interference appears reliably when the more difficult, choice response is used, but is eliminated when the less difficult, go-no go response is used (e.g., Experiments 3, 6, and 8). This suggests that intrahemispheric interference is sensitive to

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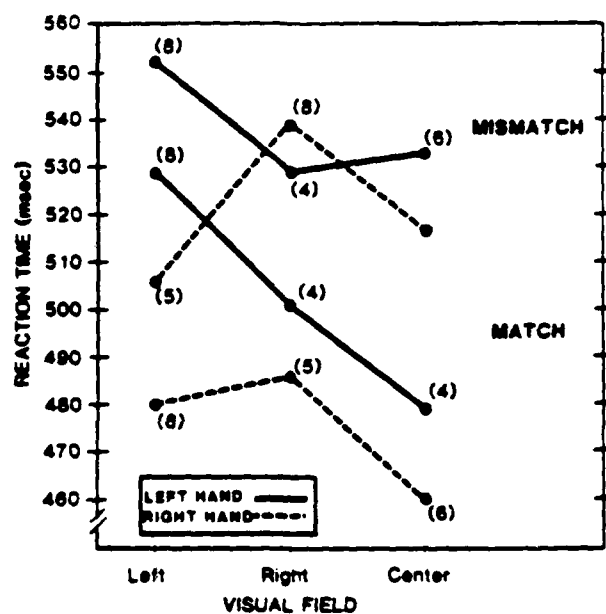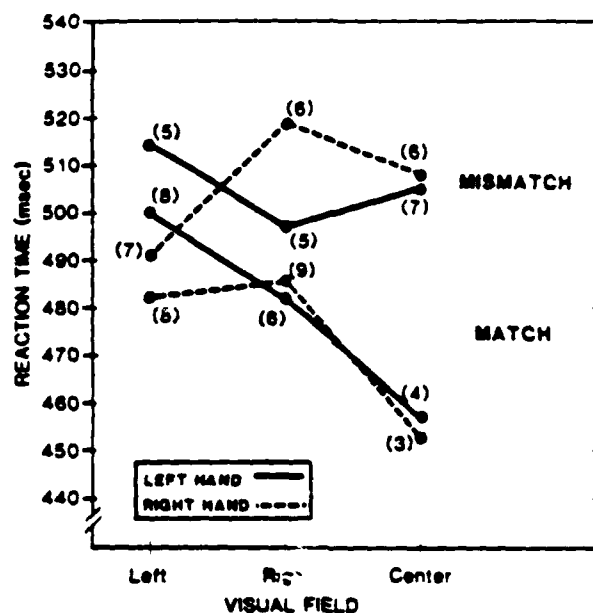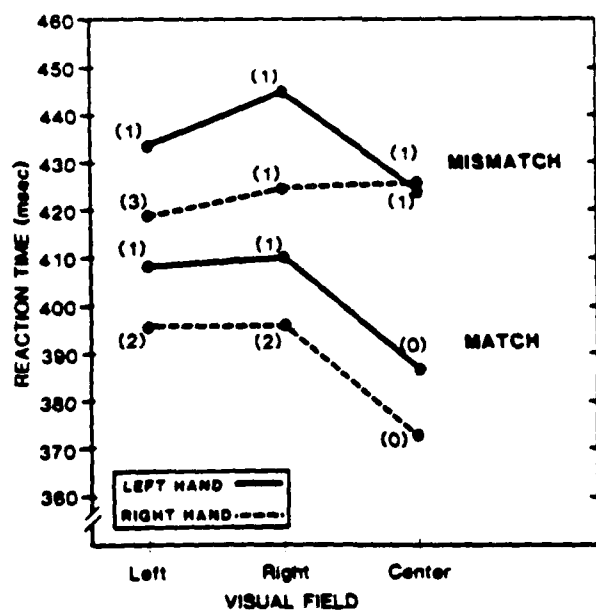
Figure 3. Major Results of Experiments 1, 2, and 3.
Percentage of error is in parenthesis.

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Results of Experiment 4.

Results of Experiment 5.

Results of Experiment 6.
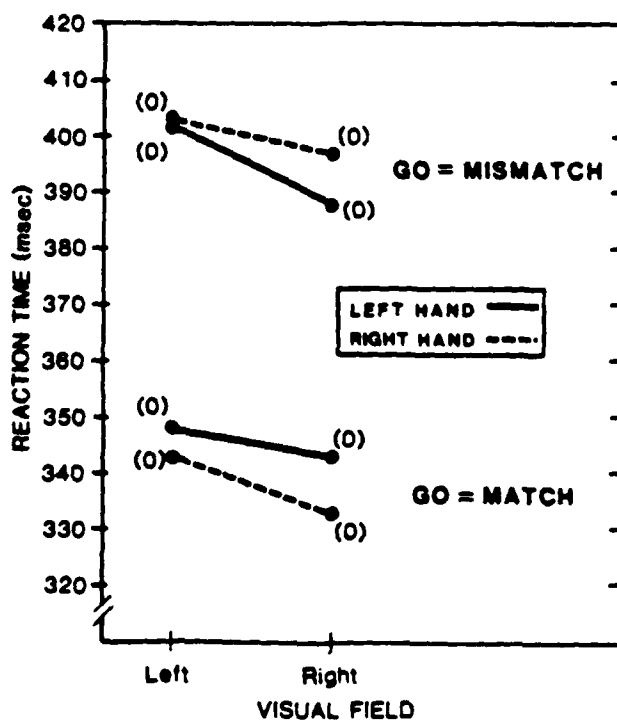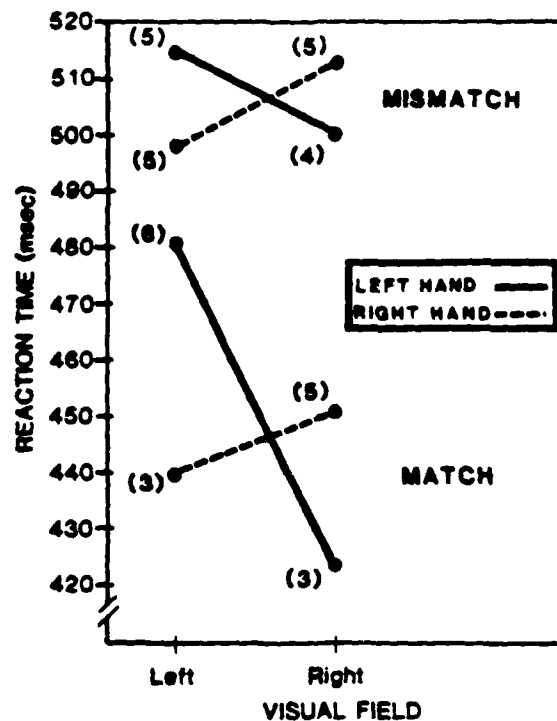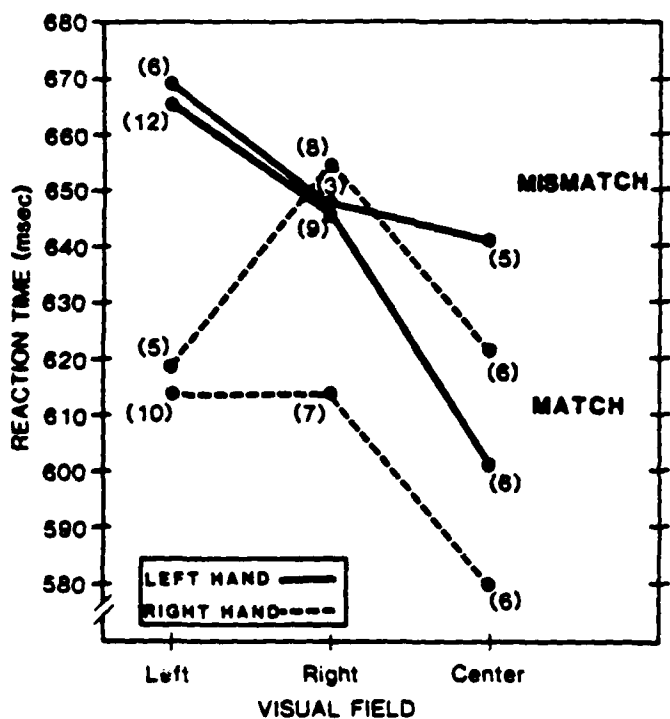
Figure 4. Results of Experiments 4 through 11.
Percentage of error is in parenthesis.
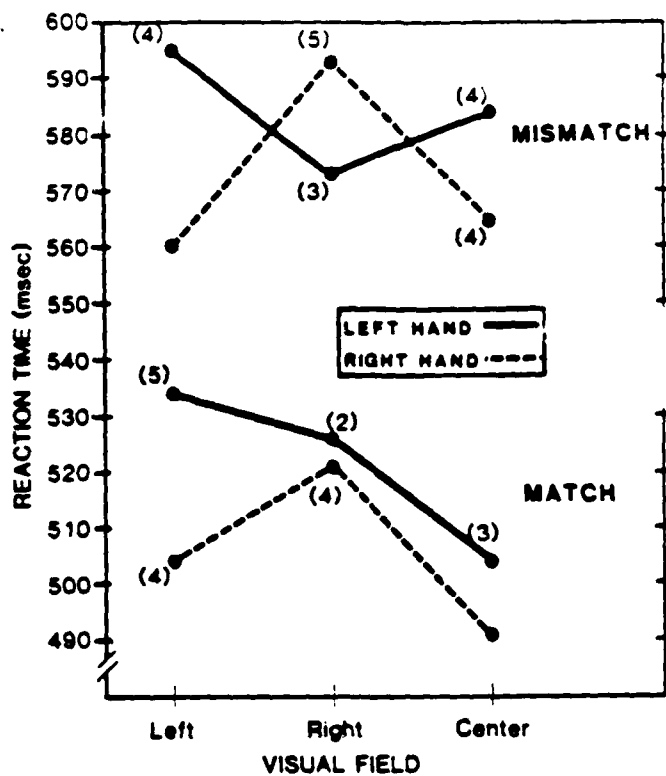
Results of Experiment 7.
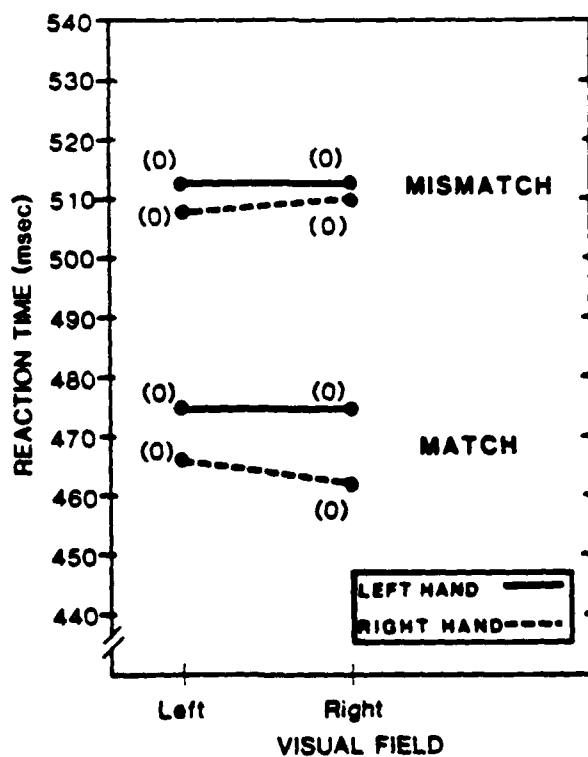
Results of Experiment 8.

Figure 4 (Continued).   Results of Experiments 4 through 11.
Percentage of error is in parenthesis.

25
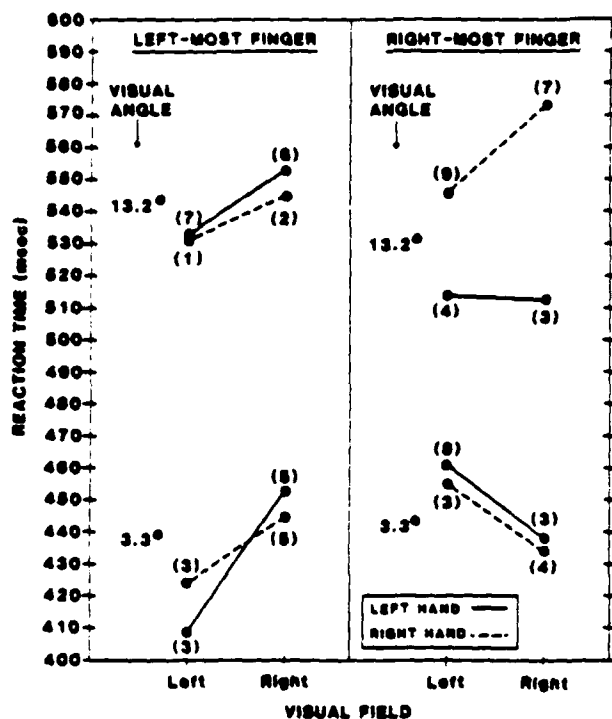
Results of Experiment 9.
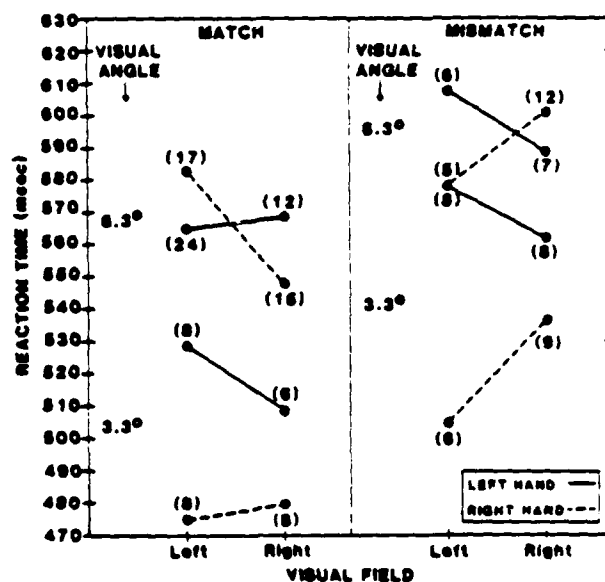
Results of Experiment 10.
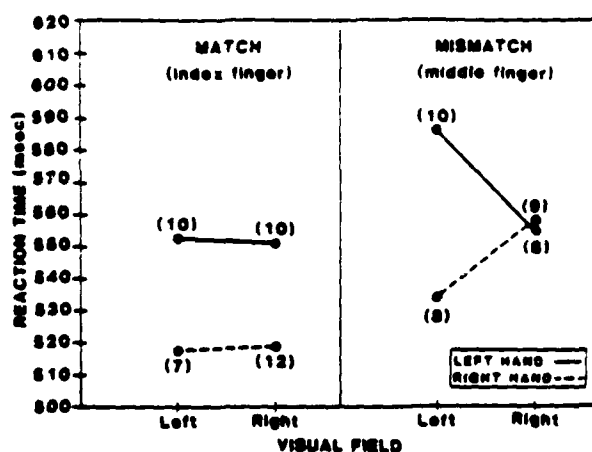
Results of Experiment 11.

Figure 4 (Concluded).   Results of Experiments 4 through 11.
Percentage of error is in parenthesis.

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degree of response processing demands and is eliminated when response processing demands are reduced.

3. Intrahemispheric interference appears to be relatively insensitive to variations in stimulus processing demands, particularly changes affecting early perceptual processing. In Norman and Bobrow's (1975) terms, interference magnitude appears relatively insensitive to "data-limiting" factors. In conditions in which it appeared, the interference magnitude did not vary when stimulus processing demands were reduced by elimination of the stimulus mask (Experiment 2) or by sequentially, rather than simultaneously, presenting stimuli to be matched (Experiment 5). When stimulus processing demands were increased by increasing the stimulus visual angle (Experiment 10) or by decreasing stimulus duration (Experiment 11), the interference magnitude was also unaffected.

4. There is a variety of indirect evidence that changes in more central processing demands, including those related to stimulus processing, influence whether evidence of intrahemispheric interference appears. Experiment 9 indicated that evidence of interference is eliminated in a task involving recognition of single stimulus letters, rather than matching of stimulus pairs, even when a choice response is used. It was hypothesized that differences in the central processing demands of the two tasks might account for the differences, with the letter recognition task involving more simple processing.

Another effect which was initially interpreted in terms of differences in central processing demands was the tendency for interference to be more reliably associated with mismatch rather than match responses. It was suggested that this indicated that interference was related to degree of processing demands in that mismatch decisions have been interpreted as being more complex than match decisions (Bamber, 1969; Krueger, 1978). However, this interpretation is strongly questioned by the results of Experiment 12. Experiment 12 required subjects to use what will be called Response Assignment 2, indicating match on the middle finger and mismatch on the index finger. In this experiment, evidence of interference appeared for matches, but not for mismatches. Subsequent experiments have also indicated that response assignment is a critical factor. Since examination of these effects has been the focus of recent work, further details will be discussed in Section IV.

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SECTION IV

DESCRIPTION OF EXPERIMENTS 13 THROUGH 17

A. Introduction

This section provides details of Experiments 13 through 17, which were conducted since the publication of the Second Interim Report in January, 1984. The research took a somewhat anticipated turn because of the discovery that a simple change in response assignment, within two-choice response conditions, had major effects on evidence of intrahemispheric interference. It therefore became necessary to perform several experiments investigating the nature of the response assignment effect. In addition, Experiment 17 investigated whether intrahemispheric interference affected performance of a task at which the left hemisphere is reliably superior, among right-handed subjects.

Since Experiments 13 through 17 were similar in many respects, their common methodology is first described. Then, the purpose, specific procedures, and results for each experiment are presented. For purposes of completeness the presentation of results is fairly detailed. The discussion of each experiment focuses on results of major interest to the present research.

B. Methodology Common to Experiments 13 Through 17

1. Subjects

Subjects were experimentally naive, right-handed Georgia Tech male undergraduates. Only right-handed male subjects were tested because such a population has less heterogeneous brain organization (Bryden, 1982), a factor which could confound the effects of interest or add variability to the data. Only individuals with right-handed parents were tested. Handedness was also assessed through use of a modified Edinburgh Handedness Inventory (Oldfield, 1971) presented in Appendix A.

Both foveal and peripheral acuity were assessed to insure that subjects had at least 20/40 vision at a distance of twenty feet and accurate peripheral acuity to at least five degrees, either corrected or uncorrected. Eye dominance was also measured, although the relationship between this factor and brain organization is unclear (Bryden, 1982).

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Table 3 indicates the age, handedness scores, and eye dominance for subjects tested in Experiments 13 through 17. There are no pronounced differences between samples, with the exception that there was a greater percentage of right eye dominant subjects in Experiment 17.

Subjects were paid $15.00 for their participation.

2. Apparatus

An IBM Personal Computer with a Tecmar Graphics Board was used to present stimuli on a Quadchrome Color Monitor. The computer also controlled all interval timing, and recorded reaction time in msec. The color monitor was set to display white stimuli on a dark gray background. The graphics-controlling software was specifically designed to minimize and control time variations due to the 16.67 msec refresh time of the color monitor's cathode ray tube.

The subject sat at a table before the display and placed his head in a headrest which positioned his eyes 50.0 cm away from the center of the display. The subject responded by using two 4.9 x 2.0 cm microswitch keys mounted on a keyboard sitting on the table. The testing room was dimly lit.

3. Stimuli

The stimuli described below were used in Experiments 13 through 16. Those used in Experiment 17 will be described in the discussion of that experiment. The stimuli consisted of pairs of computer-generated upper case letters selected from the set X, M, T, and H. Each letter measured 1.2 x 1.0 cm and subtended 0.9 degrees of horizontal visual angle. Each stimulus pair was vertically arranged with a separation of 1.6 cm between the bottom of the upper letter and the top of the lower letter. The letters were positioned such that the inner edges of letters presented in the right or left visual field occurred at 3.2 degrees of visual angle. All pairs were centered around the horizontal axis of the fixation point.

TABLE 3

Subjects in Experiments 13 Through 17.

Experiment	Number	Handedness Score		Age (Years)		Eye Dominance Frequency		
		Mean	S.D.[1]	Mean	S.D.[1]	Right	Left	None
13	24	51.0	3.9	20.0	1.8	12	1	11
14	24	51.1	3.8	19.7	1.6	11	5	8
15	24	51.9	4.4	20.8	2.3	10	6	8
16	24	49.6	4.1	19.0	1.4	12	4	8
17	32	51.2	3.6	19.7	1.3	24	8	0

[1] S.D. = Standard deviation

C. Experiment 13A

1. Introduction

Experiment 13A was the initial study making use of the IBM Personal Computer-based experimental system. Experiments 1 thorugh 12 have been conducted using a Perkin-Elmer Interdata 8/32 computer and a Conrac Color monitor. To insure the operational identity of the new system with that used previously, it was advisable to repeat certain test conditions on the new system and compare obtained data with those gathered previously. Experiment 13A was designed to accomplish this purpose by repeating the procedures used in Experiment 1 (see First Interim Report, April, 1983) to see if the results replicated.

2. Method

Experimental Design. Subjects were tested in two test sessions, each lasting approximately one hour and occurring on successive days. Subjects used the right hand in one session and the left hand in the other session, with hand order counterbalanced over subjects. In each test session subjects were exposed to six blocks of test trials, each block consisting of 60 test trials.

Within each block, half of the letter pairs were "match" pairs (letters identical) and half were "mismatch" pairs (letters not identical). Each stimulus type appeared with equal frequency in the left, right or central visual field. Stimulus type and stimulus visual field were randomly ordered within a block.

Procedure. Each test session consisted of 6 blocks of 60 trials. The first block was a practice block. Each block began with the appearance of the word "READY" in the center of the screen. Each trial proceeded as follows. A small fixation plus appeared in the center of the screen. The subject was instructed to carefully fixate on the plus, and when fixated to press both response keys to initiate the trial. The requirement to press both keys was designed to eliminate biases toward responding to a particular key. The fixation point remained on, but 500 msec later a stimulus pair appeared for

150 msec in the left, right, or center visual field. The stimulus pair was followed by a 125 msec mask. The mask of each letter was formed by simultaneously plotting the four letters, one over the other. The lines in the mask thus overlapped all the possible line features composing the letters. The fixation plus disappeared with the offset of the mask.

The subject's task was to judge whether the stimulus pair was a match or a mismatch, and to indicate a match by a keypress of the index finger, and a mismatch by a keypress of the middle finger. The keyboard was positioned below the center of the display, directly below the fixation plus, with one key to each side of the plus. Following the response, performance feedback appeared for one second in the center of the screen above the former location of the fixation point. For correct responses, the subject's reaction time appeared. If the response had been incorrect, the word "ERROR" appeared. The plus then reappeared signalling the beginning of a new trial.

Subjects were encouraged to compare the letter shapes, and to avoid naming them. The importance of fixating centrally at all times, except when looking at performance feedback, was emphasized. Subjects were told to respond quickly, but to try to make fewer than six errors per trial block. At the end of each block they were given feedback on their reaction time and error rate for that block, and were encouraged to slow down or speed up depending on their error rate.

3. Results

For each subject, the median reaction time and average percentage of error were computed for each stimulus type by visual field by responding hand condition, collapsing over trial blocks and eliminating the first practice block. The means of the subject data are shown in Figure 5. Individual subject data is in Appendix B.

An analysis of variance (ANOVA) was done on reaction time, using stimulus type, visual field, responding hand, and hand order as variables. Since primary interest was in differences between left and right visual field conditions, central visual field trials were included in one ANOVA and excluded from the second.
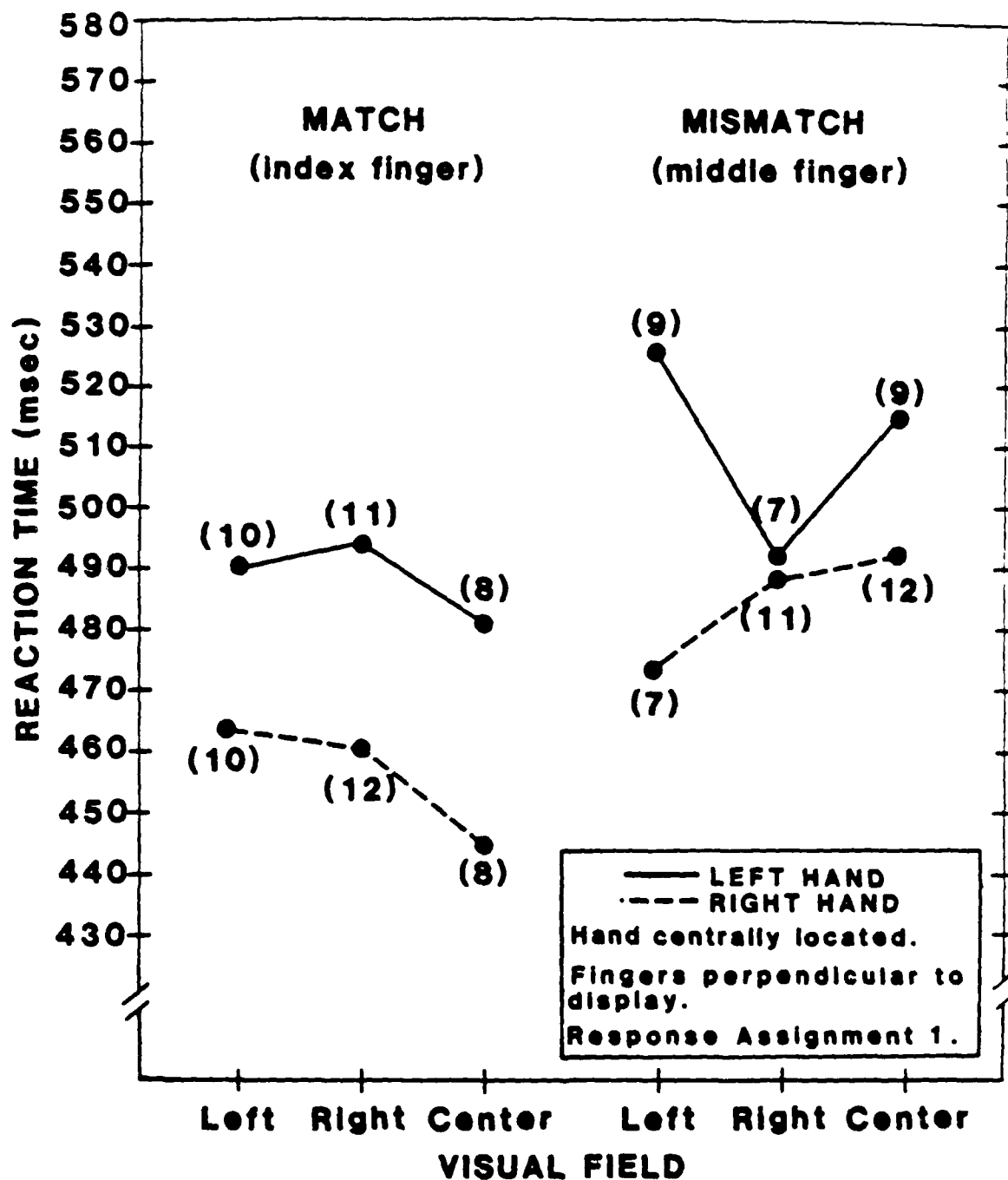
Figure 5. Major Results of Experiment 13A.
Percentage of error is in parenthesis.

The results from the two ANOVAs were highly consistent. The results from the ANOVA excluding central visual field data are discussed below.

Right hand performance (471 msec) was faster than left hand performance (500 msec, $F(1,10) = 11.18$, $p < 0.01$). This trend had been apparent in previous experiments, although it had not reached significance.

As in previous studies, match responses (476 msec) were faster than mismatch responses (495 msec, $F(1,10) = 6.26$, $p < 0.03$). There was a significant hand by hand order interaction ($F(1,10) = 24.00$, $p < 0.01$) shown in Table 4. The interaction indicates that the faster of the two hands was the one used during the second session, reflecting practice effects.

Of major interest were the presence of a significant responding hand by visual field interaction ($F(1,10 = 5.11$, $p < 0.05$), and of a significant responding hand by visual field by stimulus type interaction ($F(1,10) = 6.19$, $p < 0.05$). As can be seen in Figure 5, for mismatch responses, reaction time was faster for the visual field contralateral to the responding hand. This effect was not seen for match responses. T-tests of the interaction scores (see Table 1 for interaction score computation) indicated that the responding hand by visual field interaction was significant for mismatches ($t(11) = 2.78$, $p < 0.01$) but not for matches.

An ANOVA was also done on an arcsine transformation of the percentage of error, excluding center visual field data. The only significant effect was the hand order by stimulus type interaction ($F(1,10) = 6.02$, $p < 0.05$). For the left to right hand order, the error rate was seven percent and did not vary with stimulus type. For the right to left order, more errors were made on match trials (twelve percent) than on mismatch trials (six percent).

Interestingly, however, examination of the reaction time data indicates that the advantage of match over mismatch pairs was, in fact, greater in the left to right hand order (26 msec) than in the opposite hand order (11 msec). This indicates that the overall reaction time advantage for match responses was not due to a speed-accuracy tradeoff. The error data provided no evidence that speed-accuracy tradeoffs might be responsible for any of the reaction time effects described earlier.

TABLE 4

Experiment 13A: Hand by Hand Order Interaction.
Reaction time in msec.

Hand Order →	Left Hand In Session 1	Right Hand In Session 1
Hand ↓		
Left	519	481
Right	447	495

4. Discussion

Comparison of the results of Experiment 13A with those of Experiment 1 indicates that the most important effects were replicated. For purposes of comparison, the results of Experiment 1 are indicated in Figure 6. Both Experiments 1 and 13A show reliable effects of stimulus type, with matches being faster than mismatches. It has been suggested that this is because match decision-making involves less complex processing (Bamber, 1969; Krueger, 1979).

Both experiments also provide no evidence of a reliable difference as a function of visual field, but do indicate a reliable interaction between visual field and responding hand. Response tends to be slower for stimuli appearing in the visual field ipsilateral to the responding hand. This is evidence of intrahemispheric interference between stimulus and response processing demands associated with the same hemisphere.

The only differences between the results of the two experiments are subtle ones. In Experiment 1, the stimulus type by responding hand by visual field interaction was not significant, as it was in Experiment 13A. However, t-tests of the interaction scores of Experiment 1 indicate a similar trend. In Experiment 1, the interaction is highly significant for mismatches ($t(9) = 3.3$, $p < 0.01$) but only approaches significance for matches ($t(9) = 1.60$, $0.10 < p > 0.05$). Thus, the results of Experiment 1 tend to be consistent with those of Experiment 13A, in suggesting that intrahemispheric interference more reliably effects mismatch decisions. The greater complexity of determining mismatch decisions may make them more vulnerable to interference effects.

In Experiment 1 right hand responses were not significantly faster than left hand responses, as occurred in Experiment 13A. There was, however, a trend in that direction ($p < 0.12$) in Experiment 1. Experiment 13A performance tends, in general, to be somewhat faster, but also less accurate than that in Experiment 1. This suggests that subjects were paying more attention to speed, and less attention to accuracy in Experiment 13A. However, accuracy averaged below the ten percent error rate dictated by instruction.
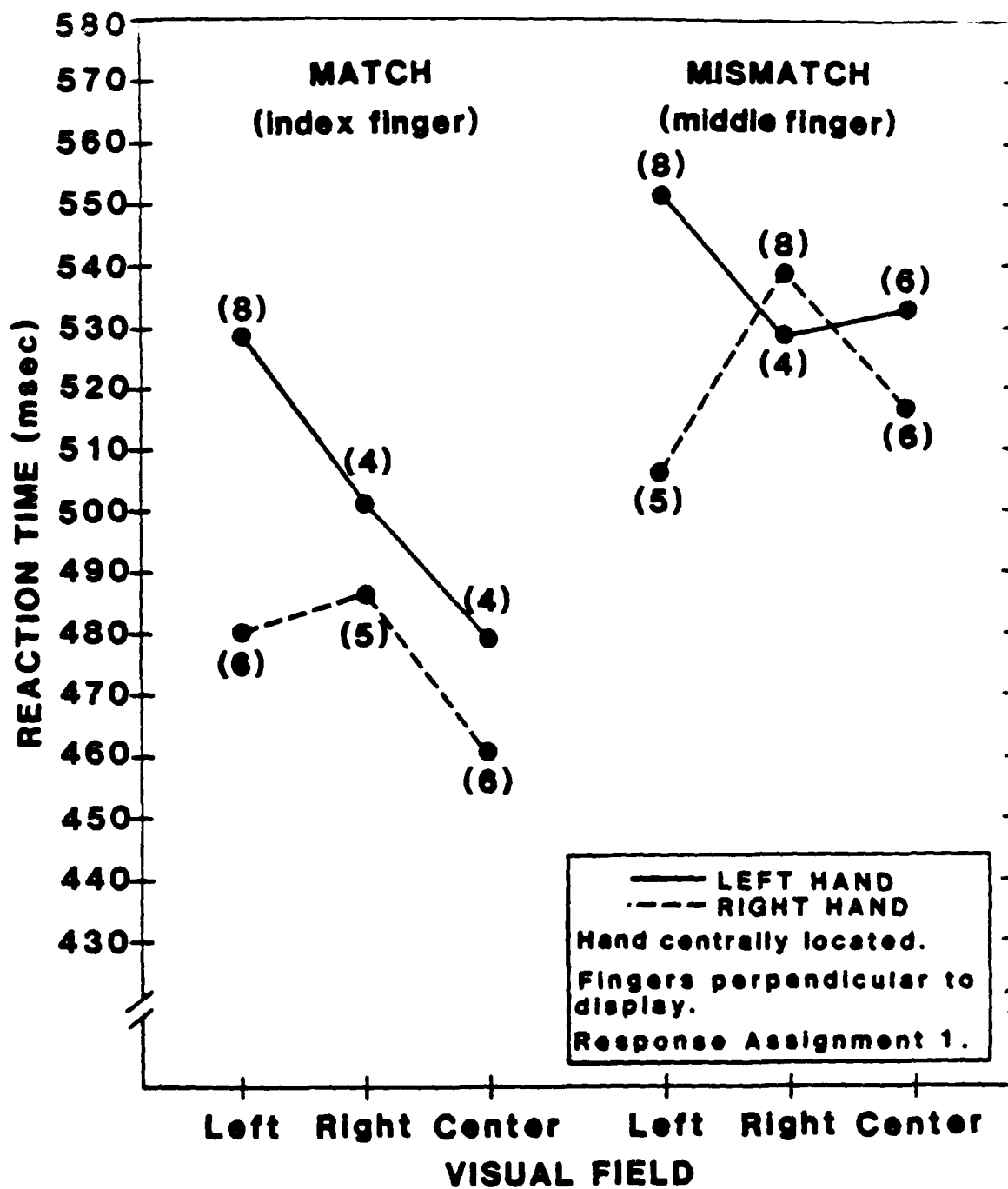
Figure 6. Major Results of Experiment 1.
Percentage of error is in parenthesis.

In summary, then, Experiment 13A replicates the major results of Experiment 1 and suggests that the new experimental set-up is operationally equivalent to that used previously.

D. Experiment 13B

1. Introduction

The purpose of Experiment 13B was to examine the reliability of the results of Experiment 12, performed on the previous testing system. The purpose of Experiment 12 had been to examine the importance of the nature of the response assignment and of the identity of the responding finger in determining intrahemispheric interference. Experiments 1 through 11 used what will be called Response Assignment 1 (RA1), assigning match decisions to the index finger response and mismatch decisions to the middle finger. In general, the middle finger mismatch responses provided more reliable effects of intrahemispheric interference.

In Experiment 12, subjects were instructed to use Response Assignment 2 (RA2), which reversed the assignments of RA1. The results indicated that while evidence of interference persisted for the middle finger responses (this time match), that evidence was absent for the index finger (mismatch) responses. This result implies that it is the finger identity (middle or index), and not the decision identity (match or mismatch) that is determining whether there is evidence of intrahemispheric interference.

This is very difficult to explain, particularly given the apparent equality of index and middle finger response, in terms of skill or speed (Annett & Annett, 1979). It was decided to determine the reliability of the result before further investigating it.

2. Method

Experimental Design. The design was identical to that of Experiment 13A.

Procedure. The procedure was identical to that of Experiment 13A, with the following exception. Subjects were instructed to use Response Assignment 2 (RA2), indicating a match response by a keypress of the middle finger and a mismatch response by a keypress of the index finger.

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3. Results

For each subject, the median reaction time and average percent error were computed for each stimulus type by visual field by responding hand condition, collapsing over trial blocks and eliminating the first practice block. These data are shown in Figure 7. Individual subject medians are presented in Appendix C.

The subject means were included in two ANOVAS, one including all conditions and the second excluding center visual field data, since major interest is in left-right visual field differences. The significant effects and interactions were identical for the two analyses. The ANOVA excluding center visual field data is discussed below.

As in Experiment 13A, match responses (534 msec) were faster than mismatch responses (566 msec, F (1,10 = 7.93, p < 0.05). There was a significant responding hand by hand order interaction (F (1,10) = 9.92, p < 0.03) shown in Table 5. As in Experiment 13A, the hand used during the second session was faster than that used during the first, reflecting practice effects. There was also a significant interaction between responding hand order and visual field (F (1,10) = 6.14, p < 0.05), shown in Table 6. When the left hand order was used first, there tended overall to be a left visual field advantage. Examination of the data indicates that, although significant for the data collapsed over the left and right hand sessions, the effect is largely due to a large (50 msec) left visual field advantage that occurs when the left hand is used in the first session.

Of greater interest was a significant responding hand by visual field interaction (F (1,10) = 10.15, p < 0.01). There tends to be an advantage for the visual field ipsilateral to the responding hand. As Figure 7 indicates, this interaction is somewhat less pronounced for matches, especially for the right hand. T-tests of the interaction scores indicate that the interaction is significant for mismatches (t(1,11) = 2.70, p < 0.05), but only tended toward significance for matches (p < 0.10).

An ANOVA was also done for an arcsine transformation of the percentage of error, excluding center visual field data. There were no significant effects or interactions.
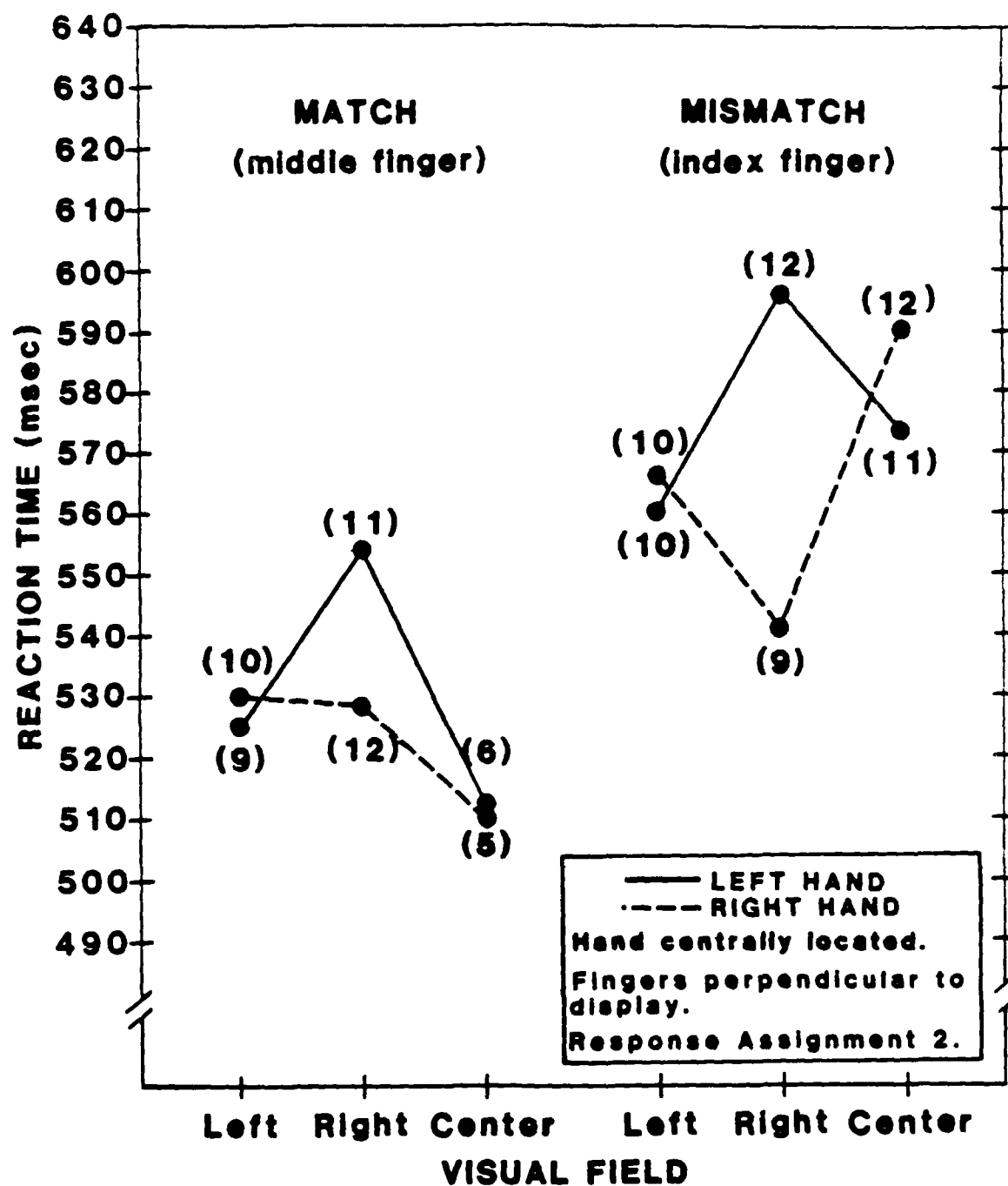
Figure 7.   Major Results of Experiment 13B.
            Percentage of error is in parenthesis.

TABLE 5

Experiment 13B: Hand by Hand Order Interaction.
Reaction time in msec.

Hand Order →	Left Hand in Session 1	Right Hand in Session 2
Hand ↓		
Left	617	501
Right	516	566

TABLE 6

Experiment 13B: Hand Order by Visual Field Interaction.
Reaction time in msec.

Hand Order →	Left Hand in Session 1	Right Hand in Session 2
Visual Field ↓		
Left	555	535
Right	578	532

4. Discussion

Experiment 13B was intended to examine the impact of response assignment on the responding hand by visual field interaction that has been used as evidence of intrahemispheric interference. Experiment 13B repeated the method of Experiment 12. For purposes of comparison, the results of Experiment 12 are shown in Figure 8. A comparison of Figures 7 and 8 indicates that overall reaction time and error rate are similar for the two experiments. For mismatch responses, the responding hand by visual field interactions are similar, suggesting an advantage for stimuli in the visual field ipsilateral to the responding hand.

For match responses, however, the interaction patterns are not similar, with performance favoring stimuli in the contralateral visual field in Experiment 12 and favoring the ipsilateral visual field in Experiment 13B. The main difference is in left hand performance; right hand match performance is similar for the two experiments. The reason for the difference in left hand performance is not clear. However, the results of the two experiments further testify to the fact that mismatch responses produce more reliable effects than do match responses.

The distinctiveness of match versus mismatch responses is further evidenced by the fact that even when response assignment is reversed, match responses remain significantly faster than mismatch responses. The stability of these effects rules out the possibility that faster responding by the index finger could account for the reaction time advantage of match responses when RA1 was used. The advantage of match over mismatch reaction time lends support to the idea that match decision-making is less complex.

Since evidence of intrahemispheric interference did not occur in Experiment 13B the results do not clarify the issue of whether stimulus type (match-mismatch) or responding finger (index-middle) is more important in determining interference. The fact that interference has appeared less reliably in both of the experiments involving RA2 suggests that response assignment may be a critical factor. It also appears that mismatch responses are associated with more reliable response assignment effects, these being an advantage for the visual field contralateral to the responding hand when RA1 is used, and for the visual field ipsilateral to the responding hand when RA2

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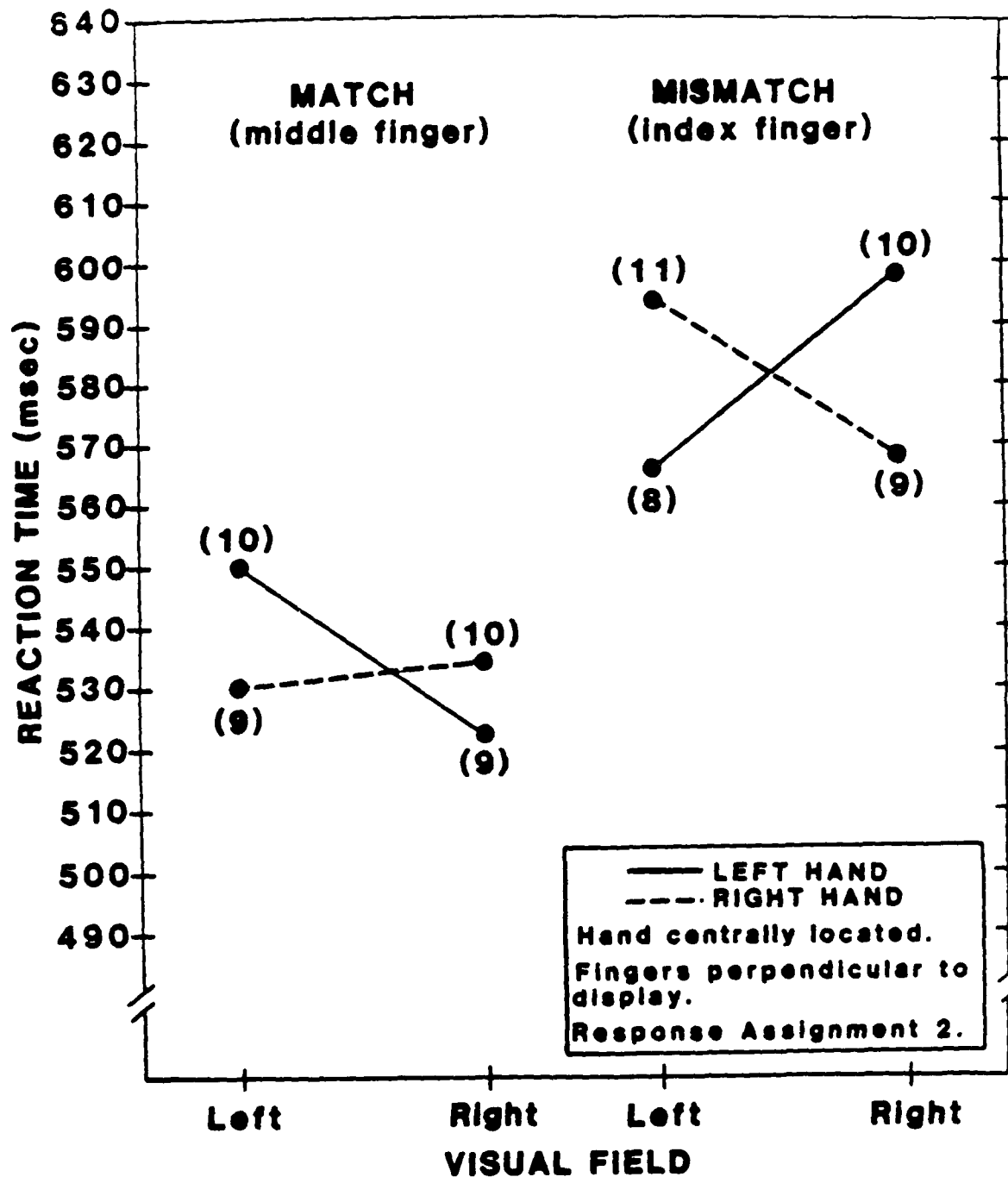
Figure 8.   Major Results of Experiment 12.
            Percentage of error is in parenthesis.

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is used. Match responses are not associated with replicable effects for either response assignment.

When compared with the results of Experiments 1 and 13A, the results of Experiments 12 and 13B suggest that RA2 is more difficult than RA1. Although the error rate is comparable in the two pairs of experiments, reaction time is considerably longer in Experiments 12 and 13B. The greater difficulty of RA2 could explain why practice effects are larger in these experiments.

The difference due to response assignment was not predicted, but the effects are quite intriguing and have some important practical implications. In most two-choice unimanual experiments and tasks, little attention is paid to the decision-finger assignment. The present results imply that this assignment can significantly affect the overall speed of performance. In the present case, there appears to be an advantage when the faster decision (i.e., match) is assigned to the index finger and the slower decision (i.e., mismatch) is assigned to the middle finger, than when the assignment is reversed. This idea will receive further discussion.

The most significant result of Experiment 13B, in terms of clarifying factors determining intrahemispheric interference, is the absence of the advantage for the stimulus contralateral to the responding hand, and the presence instead of an ipsilateral advantage. This result is significant in that it seems to force qualification of the hypothesis that the presence and/or magnitude of interference is directly related to the general difficulty of processing demands. This hypothesis is brought into question because, although there is evidence that RA2 is more difficult than RA1, effects associated with interference are largely eliminated when RA2 is used.

The question of what is causing the tendency toward an ipsilateral visual field advantage when RA2 is used is also of considerable interest. Two possibilities have been considered. The first is in terms of facilitatory effects between processing activities associated with the same hemisphere. The second is in terms of responding finger or hand-related stimulus response compatibility effects. Further description of these ideas will be presented in the discussion of Experiment 15, which tests related hypotheses.

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E. Experiment 14

1. Introduction

One of the major results of Experiments 1 through 8 was that evidence of intrahemispheric interference was eliminated when an index finger go-no go response was used, rather than a choice response. This was interpreted as indicating that interference magnitude was sensitive to response processing demands, being eliminated when such processing demands were reduced as when the simpler go-no go response was used.

The results of Experiment 12 question this interpretation because they suggest that evidence of interference is more reliably associated with middle, rather than index finger response, regardless of response identity (match or mismatch). This means that the elimination of evidence of interference in the earlier go-no go studies might be due to use of the index finger to respond, rather than to reduced processing demands. Even though the results of Experiment 12 were not entirely replicated in Experiment 13B, it was decided to further examine the importance of the responding finger identity in the go-no go conditions.

In Experiment 14, subjects performed the letter-matching task with a go-no go response. The responding finger was systematically varied to examine its impact on the appearance of intrahemispheric interference.

2. Method

Experimental Design. Subjects were randomly assigned to one of four groups: index finger "go" response for match pairs, middle finger "go" response for match pairs, index finger "go" response for mismatch "pairs, middle finger "go" response for mismatch pairs. Within each of these groups, half of the subjects used their left hand during the first test session and half used the right hand. The variables of stimulus type and visual field were manipulated within subjects as described for Experiment 13A.

Procedure. The procedure was identical to that used in Experiment 13A and 13B, with the following exception. Each subject was assigned a "go" response (match or mismatch) and a finger to be used in making that response (index or middle). Subjects were told to withhold response on trials on which "no go" stimulus pairs appeared.

3. Results and Discussion

For each subject the median reaction time and average percentage of error were computed for each responding hand by visual field condition, collapsing over trial blocks and eliminating the first practice block. These data are shown in Figure 9, separated by finger used (index or middle) and go response (match or mismatch). Individual subject data are included in Appendix D.

The median reaction times were subject to an ANOVA, with hand order, go response, and finger as between-subjects variables, and visual field and hand as within-subjects variables. One ANOVA was done including center visual field trials. Since major interest is in left versus right visual field effects, a second ANOVA was done excluding center visual field trials. The two ANOVAs indicated identical effects, with the exception that the visual field main effect was significant only in the ANOVA including center visual field data (F(2,16) = 6.28, p < 0.01). This indicates that responses to center visual field stimuli were significantly faster than those to left or right visual field stimuli.

The results of the ANOVA excluding center visual field trials indicated the following. First, as can be seen in Figure 9, there is no significant interaction between hand, visual field, finger, and go response. This replicates the results of Experiment 3, and supports the idea that the absence of evidence of intrahemispheric interference in Experiments 3, 6, and 8 did not occur because the go response involved use of only the index finger. Of special note is the absence of a hand by visual field interaction even for middle finger mismatch responses, which have shown the most consistent effects of interference in the two-choice experiments.

The ANOVA indicated that match responses (382 msec) were faster than mismatch responses (426 msec, F(1,16) = 8.99, p < 0.01). There was an interaction between go response and visual field (F(1,16) = 5.49, p < 0.05). When match was the go response, right visual field responses (380 msec) were similar in speed to left visual field responses (384 msec). However, when go response was for mismatch pairs, left visual field responses (422 msec) tended to be faster than right visual field responses (431 msec).

This pattern suggests a right hemisphere advantage for judging mismatches. This is inconsistent with previous studies suggesting a left

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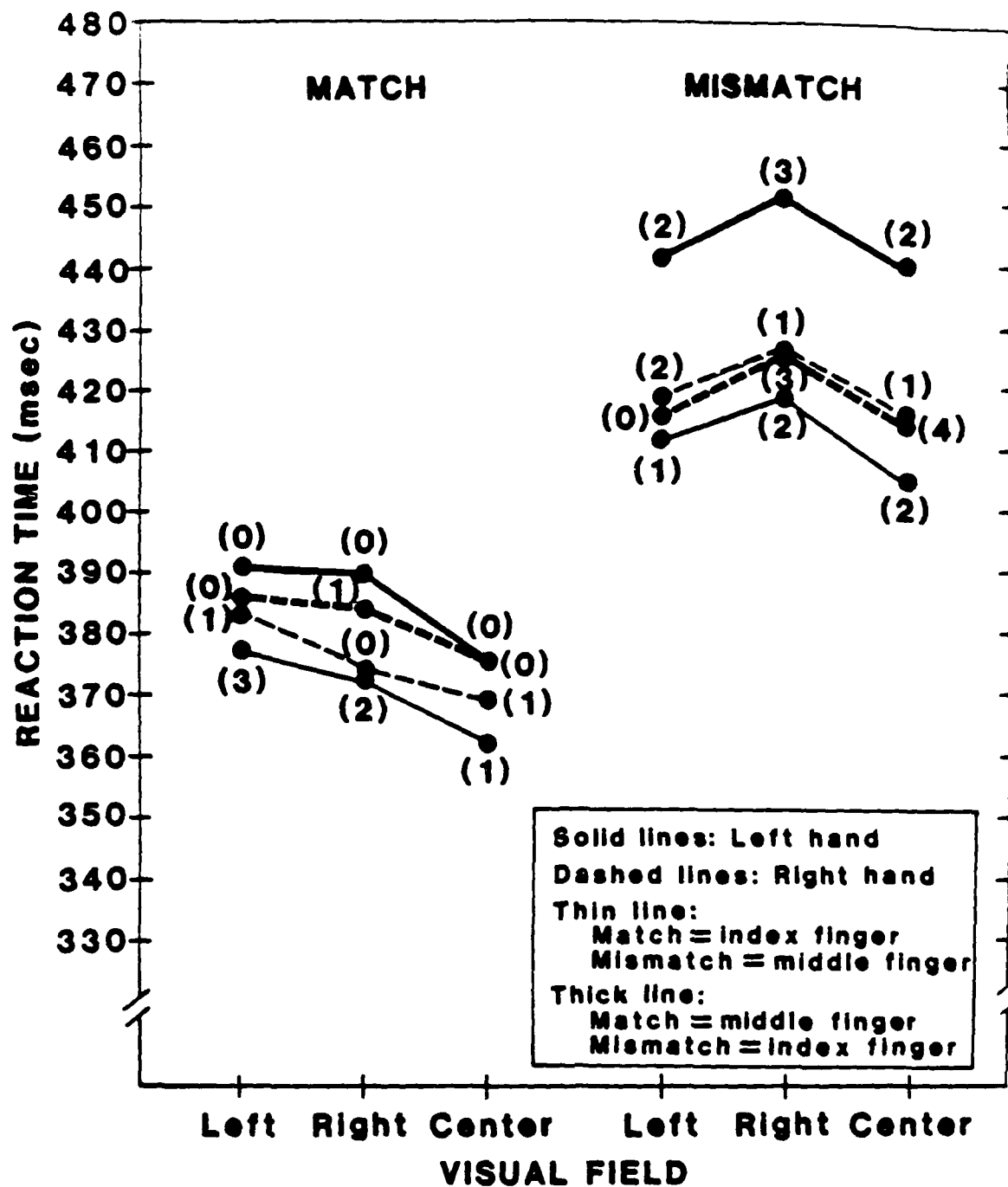
Figure 9. Major Results of Experiment 14.
Percentage of error is in parenthesis.

hemisphere advantage for mismatch judgments (Egeth & Epstein, 1972). The left hemisphere advantage has been interpreted as reflecting the left hemisphere's superior capability for the analytic processing hypothesized as sometimes necessary for confirming detection of a difference.

In the present case, however, the letter differences were obvious, so lack of an advantage for the more "analytic" hemisphere is not surprising. In fact, the left visual field advantage may reflect a right hemisphere advantage in making use of gross, low frequency information (Sergent, 1983) which may have been sufficient for detecting mismatches in the present case.

There was a variety of significant interactions involving the hand order variable, including hand order by hand ($F(1,16) = 11.97$, $p < 0.01$) and hand order by hand by visual field ($F(1,16) = 6.71$, $p < 0.05$), and hand order by hand by visual field by go response ($F(1,16) = 4.14$, $p < 0.01$). Relevant data are shown in Table 7. The hand by hand order interaction indicates that the hand used in the second test session was faster than that used in the first session. The pattern of the hand by hand order by visual field interaction suggests that, although the two hands performed similarly when used during the second session, there were between-hand differences in performance during the first test session. During the first test session, the left hand was generally slower than the right hand and showed a larger tendency toward a left visual field advantage.

The hand by hand order by visual field by go response interaction adds further clarification. The visual field differences are generally small (< 10 msec), with the exception of mismatch responses made during the first session. In this case, for either hand, there tends to be a left visual field advantage, with a somewhat greater advantage for the left hand. First session performance is largely responsible for the left visual field advantage for mismatches observed in discussing the visual field by go response interaction.

There was also a significant hand order by go response by finger interaction ($F(1,16) = 8.89$, $p < 0.01$) shown in Table 8. When the right hand is used before the left hand, there is a consistent advantage of match reaction times over mismatch reaction times for either finger, with a larger difference for middle finger responses. In contrast, when the left hand is used before the right hand, match responses are faster than mismatch responses only for

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TABLE 7

Experiment 14: Hand by Hand Order by Visual
Field by Go Response Interaction.
Reaction time in msec.

Hand Order →		Left Before Right		Right Before Left	
Visual Field →		Left	Right	Left	Right
Go Response ↓	Hand ↓				
Match	Left	404	403	363	360
	Right	383	380	387	379
Mismatch	Left	438	461	416	411
	Right	404	407	430	446

TABLE 8

Experiment 14: Hand Order by Go Response by
Finger Response Interaction.
Reaction time in msec.

Hand Order →		Left Before Right	Right Before Left
Go Response ↓	Finger ↓		
Match	Index	369	385
	Middle	416	360
Mismatch	Index	461	407
	Middle	394	444

,

index finger responses; mismatches are faster than matches for middle finger responses.

An ANOVA was done on an arcsine transformation of percentage of error, excluding center visual field data. There were no significant main effects. There was a number of significant interactions, including go response by finger by visual field ($F(1,16) = 9.94$, $p < 0.01$) and go response by finger by visual field by hand ($F(1,16) = 4.57$, $p < 0.05$). Examination of these interactions indicated no meaningful pattern. The variation in error rate was very small, and difficult to interpret, so will not be reviewed here. The error pattern does not indicate that speed-accuracy tradeoffs had occurred.

The most important result of Experiment 14 is evidence that the absence of intrahemispheric interference seen in previous go-no go experiments was not an artifact of use of the index finger. Evidence of interference reliably disappears when a go-no go response is used regardless of the identity of the responding finger or of the response (match or mismatch).

F. Experiment 15

1. Introduction

The purpose of Experiment 15 was to investigate some alternative explanations for the interaction between responding hand and visual field observed in the earlier studies. The advantage for the visual field contralateral to the responding hand has been interpreted in terms of intrahemispheric interference. However, the change in effects when the response assignment is reversed was not predicted in terms of hemisphere-related effects, and indicates that alternative explanations should be considered.

Table 9 summarizes the findings of Experiments 12 and 13. Throughout this research, mismatch responses have been associated with more reliable effects than match responses, so alternative explanations for the variation associated with mismatch responses were the major focus. As Table 9 indicates, "different" responses are associated with a reliable advantage for stimuli in the visual field contralateral to the responding hand when RA1 is used, and an ipsilateral visual field advantage when RA2 is used.

The fact that the effects vary when there is reversal of the location of the response within the two fingers suggests that variables associated with

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TABLE 9

Summary of Findings of Experiments 12, 13A, 13B.
The favored visual field (VF) relative to
the responding hand is indicated.

Experiment	Response Assignment	Response	
		Match	Mismatch
12	Match-Middle Finger Mismatch-Index Finger	Contralateral VF* (p < 0.05)	Ipsilateral VF (p < 0.05)
13A	Match-Index Finger Mismatch-Middle Finger	No VF difference	Contralateral VF (p < 0.05)
13B	Match-Middle Finger Mismatch-Index Finger	Ipsilateral VF (p < 0.10)	Ipsilateral VF (p < 0.05)

*A contralateral VF advantage is consistent with the occurrence of intrahemi-spheric interference.

the finger could be an important factor. One possible explanation examined in Experiment 15 was that of "finger hemispace" effects. In the present case, hemispace (Bowers & Heilman, 1980) refers to the position of the finger to the right or left of the body midline. The keyboard is located such that the midline between the two keys falls along the body midline. For left hand responses, this positions the middle finger in left hemispace and the index finger in right hemispace. For right hand responses the opposite is true. For purposes of simplicity discussion will focus on left hand responses, although extensions of the described hypotheses also apply to right hand responses.

The hypothesis being considered was that performance might reflect a type of compatibility as a function of the stimulus type and the hemispatial relationship between the stimulus and the responding finger. For example, for left hand mismatch responses using RA1, the responding middle finger was in left hemispace (see Figure 10). There was a type of compatibility between the response and right visual field mismatch stimuli. There was compatibility between the nature of the stimuli (mismatch) and the hemispatial relation between the stimulus and the responding finger. For right visual field mismatch stimuli the response in the "mismatching" hemispace is the middle finger response. It is possible that, for RA1, left hand mismatch responses were faster for right visual field mismatch stimuli because those stimuli were in a mismatch hemispace. Such effects will be called "finger hemispace" effects.

Finger hemispace effects can also explain the ipsilateral visual field advantage for mismatch responses made with RA2. With RA2, mismatch responses by the left hand are made by the index finger in right hemispace. In this case, the mismatch pairs appearing in the left visual field are in the hemispace mismatching that of the responding finger. This results in an advantage for stimuli in the visual field ipsilateral to the responding hand.

A similar explanation can also be applied to certain patterns seen in match responses. For RA1, the left hand match response is made by the index finger, which is in the right hemispace. Stimuli in the right visual field are in the hemispace which "matches" that of the match response. This may result in a tendency for left hand match responses to favor right visual field stimuli, stimuli in the visual field contralateral to the responding hand.

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LEFT HEMISPACE │ RIGHT HEMISPACE

← ──── │ ──── →

Stimulus is in
right hemispace.

Responding
finger is in left
hemispace.
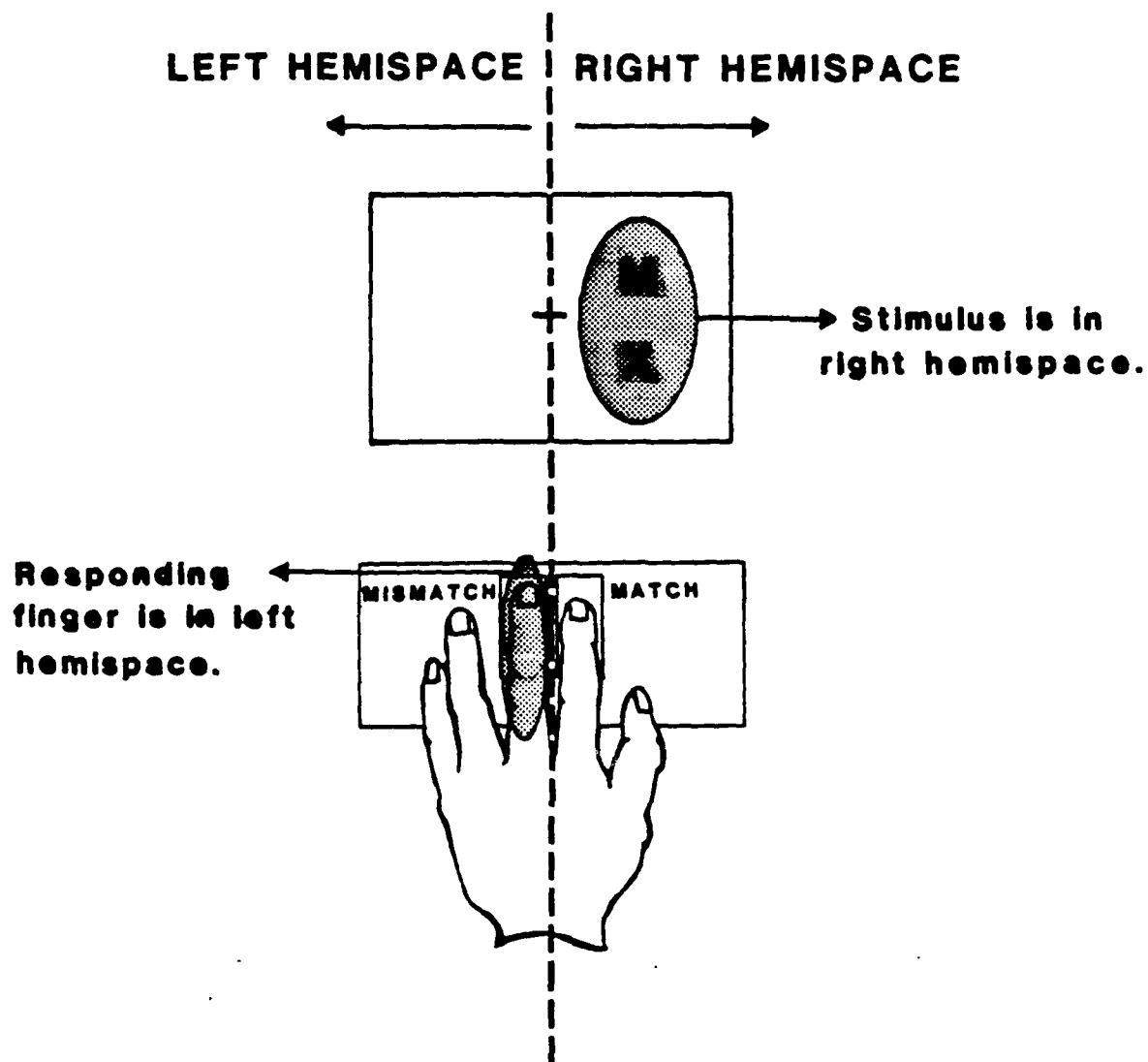
MISMATCH   MATCH

HEMISPACE EFFECT: The "mismatch" stimulus is in the
visual field whose hemispace mis-
matches that of the responding
finger.

Figure 10.   Possible Finger-Related Stimulus-Response Compatibility Effects.

Similar logic can explain why match responses made with RA2 might favor stimuli in the ipsilateral visual field, as occurred in Experiment 13B, although not in Experiment 12.

Thus, one possible explanation for the observed effects is in terms of finger hemispace effects. A second possible explanation of the results of Experiment 13B (although not of 13A) is in terms of the effects of compatibility between stimulus visual field and the perceived spatial location of the responding hand. In Experiment 13B there was an advantage for stimuli in the visual field ipsilateral to the responding hand. Such effects were not anticipated, given evidence suggesting that spatial stimulus-response spatial compatibility effects are minimized when responses are centrally located, rather than laterally located. The central response location has, in fact, been recommended to minimize such effects in visual half-field studies (Young, 1982). It is, however, possible that despite the central location of the response, subjects perceived the hand as being "left" or "right" as a function of its identity.

Experiment 15 was designed to examine both finger hemispace and response location explanations. The major manipulation in this experiment was to reposition the response in a clearly lateral location, to the left for left hand responses and to the right for right hand responses. It was hypothesized that if compatibility effects in terms of finger hemispace were important, then positioning the response in a lateral (rather than central) location should result in similar effects to those seen in Experiment 13 for middle finger responses, but different effects for index finger responses. This is because the hemispace of middle finger response does not vary when it is moved more laterally, but the hemispace of the index finger response is reversed. For example, when the left hand is centrally or laterally located, the middle finger is in left hemispace. However, when the left hand is centrally located, the index finger is in right hemispace, while for the lateral location, the index finger is in left hemispace. In other words, the responses of the index and middle finger should be more similar for the lateral response location because both fingers are then in the same hemispace.

In contrast, if compatibility effects in terms of response spatial location are important, then laterally positioning the response should increase the effects found in Experiment 13B since the lateral spatial

location becomes more pronounced. Finally, if hemisphere-related effects are the determining factor, the results of Experiment 15 should be similar to those of Experiment 13A, since there should be no change in hemisphere-related processing.

2. Method

Experimental Design. The design was similar to that used in Experiment 13A and 13B. The only difference was that, instead of one response assignment being tested before the other, the order of conditions was mixed.

Procedure. The procedure was identical to that used in Experiment 13A and 13B, with the following exception. Instead of being centrally located, with the two response keys on either side of the body midline, the response board was located on the left side for left hand conditions, and on the right side for right hand conditions. The keyboard was positioned such that the midline between the two response keys was located 12 cm to the right or left of the body midline.

3. Results and Discussion

For each subject, the median reaction time and average percentage of error were computed for each stimulus type by visual field by responding hand condition, collapsing over trial blocks and eliminating the first practice block. These data are shown in Figures 11 and 12. The individual subject data are in Appendix E.

Two separate ANOVAs were performed, each excluding center visual field data to allow the focus to be on left-right visual field differences. To allow comparison with Experiments 13A and 13B, one analysis was done for subjects using RA1 and a second analysis was done for subjects using RA2. Each of these analyses included hand order as a between-subjects factor, and visual field, stimulus type, and responding hand as within-subjects factors. The results of each ANOVA are discussed below.

Response Assignment 1. There were no significant main effects, although the right hand (520 msec) tended to be faster than the left hand (545 msec, $F(1,10) = 3.42$, $p < 0.10$). There was a significant hand order by hand interaction ($F(1,10) = 23.24$, $p < 0.01$), the faster hand being that used during the second test session. There was significant responding hand by

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Figure 11. Major Results of Experiment 15 For Response Assignment 1. Percentage of error is in parenthesis.

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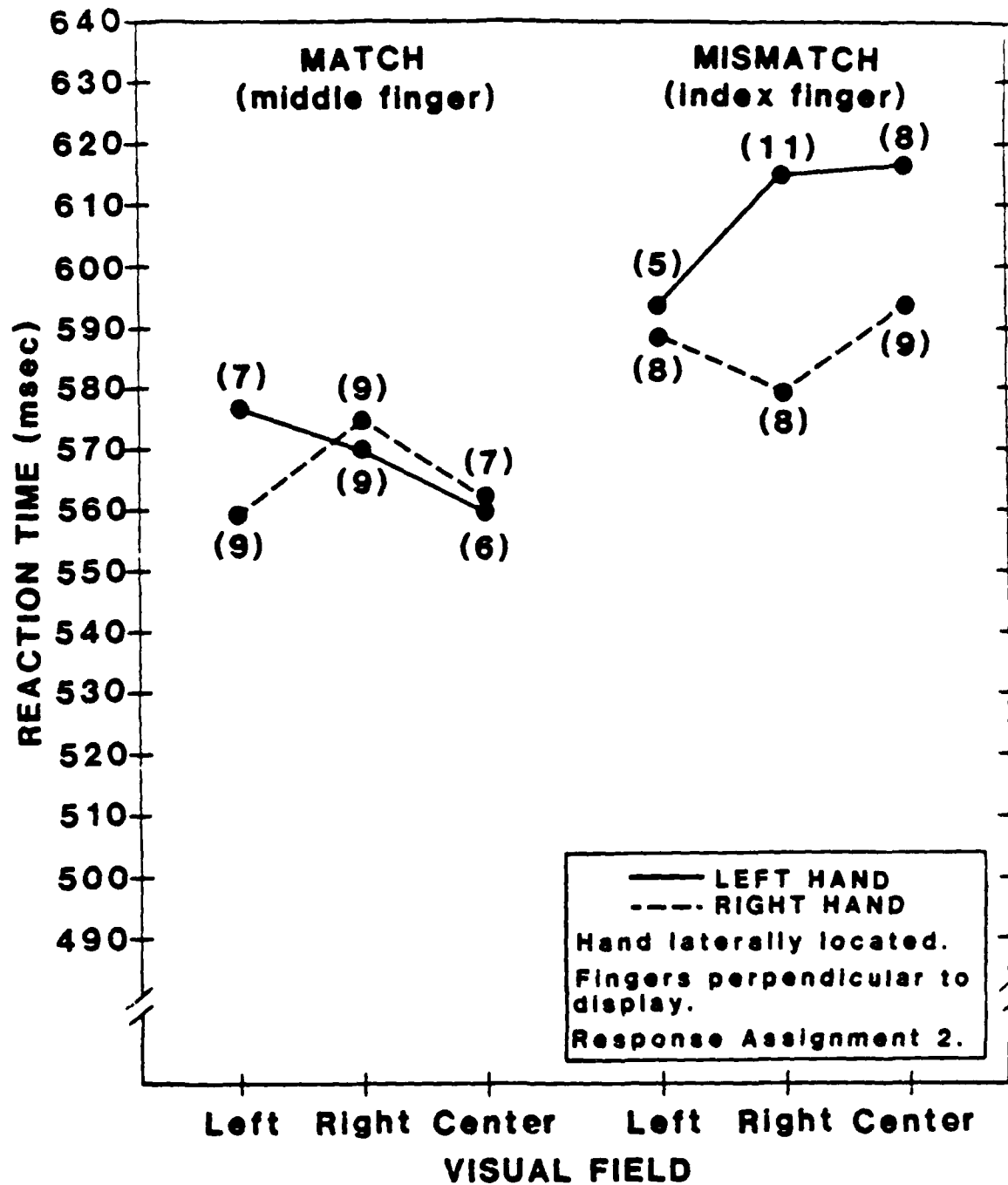
Figure 12. Major Results of Experiment 15 For Response Assignment 2.
Percentage of error is in parenthesis.

visual field interaction (F(1,10) = 9.47, p < 0.01). There is an advantage for the visual field contralateral to the responding hand. This effect appears in Figure 11 to be more pronounced for mismatches than for matches. T-tests of the interaction scores indicated that the interaction is significant for mismatches (t(11) = 1.87, p < 0.05) but not for matches.

For RA1, there was also a significant interaction between responding hand, visual field, stimulus type, and hand order (F(1,10) = 6.91, p <0.05). As can be seen in Table 10, the advantage for the visual field contralateral to the responding hand varied with stimulus type and session of responding hand use (first and second). The advantage tends to be weaker or eliminated for match responses made by subjects using the left to right hand order as well as for mismatch responses made by subjects using the right to left hand order. The reason for this variation is unclear, but suggests that additional factors are determining the advantage for the visual field contralateral to the responding hand.

A comparable ANOVA was performed on an arcsine transformation of the percentage of error. The only significant effect was that of stimulus type (F(1,10) = 12.91, p < 0.01). The percent error was greater for matches (11.3) than for mismatches (7.8). The increased error rate for matches is especially pronounced for left visual field stimuli.

Several aspects of the data are particularly interesting. First, the results for RA1 are highly similar to those of Experiment 13A even though response location was no longer central. Of particular interest is the absence of change in visual field effects for match responses which were made with the index finger. As was explained earlier, if finger hemispace is an important factor, then index finger response patterns should change when the response is lateralized. The absence of such change for RA1 questions the importance of finger hemispace.

Second, the similarity between Experiment 15 data for RA1 and Experiment 13A data also weakens the explanation that compatibility effects in terms of response location are important. If such effects were important, one might anticipate a change in visual field effects when the lateral location was a more salient factor.

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TABLE 10

Experiment 15, Response Assignment 1:
Responding Hand by Hand Order by
Stimulus Type by Visual Field Interaction.
Reaction time in msec.

Hand Order →	Left Before Right				Right Before Left			
Hand →	Left		Right		Left		Right	
Visual Field →	Left	Right	Left	Right	Left	Right	Left	Right
Stimulus Type ↓								
Match	602	604	517	490	498	473	518	546
Mismatch	605	569	486	529	497	511	535	538

A difference between Experiment 15 data for RAl and that of Experiment 13A is that in the former case match responses were similar in speed and less accurate than mismatch responses. Usually, matches have been faster and of similar accuracy. The results of Experiment 15 for RAl imply that matches become more difficult when response position was lateral. This interpretation is, however, not supported by the data for RA2, discussed below.

Response Assignment 2. This ANOVA included only those subjects tested under the match-middle finger, mismatch-index finger response assignment. The only significant main effect was that of stimulus type, with match responses (570 msec) being faster than mismatch responses (594 msec, $F(1,10) = 22.9$, $p < 0.05$). The only significant interaction was that between hand order and responding hand ($F(1,10) = 6.71$, $p < 0.05$), again indicating that the faster hand was that used during the second testing session.

Although neither the responding hand by visual field interaction nor the responding hand by visual field by stimulus type interaction was significant, Figure 12 suggests possible differences in the latter interaction for matches and mismatches. T-tests indicated that the interaction score was significant for mismatches ($t(11) = 1.87$, $p < 0.05$), but not for matches ($p > 0.20$). For mismatches, there was an advantage for the visual field ipsilateral to the responding hand.

The ANOVA of the arcsine transformation of percentage of error indicated a significant effect of visual field ($F(1,10) = 8.44$, $p < 0.05$), the percentage of error being less in the left visual field (7.3) than in the right visual field (9.3). There were no other significant effects.

The results of Experiment 15 for RA2 are very similar to those of Experiment 13B in most respects. The fact that the pattern of index finger mismatch responses did not change argues against the importance of finger hemispace. The fact that there was a reduction in the tendency for middle finger match responses to favor the visual field ipsilateral to the responding hand also supports this conclusion.

The idea that response lateral spatial location, either perceived or actual, determines the visual field effects is also not supported. There was no increase in the magnitude or reliability of the tendency for performance to favor stimuli in the visual field ipsilateral to the responding hand.

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In conclusion, the results of Experiment 15 do not support the ideas that either finger hemispace or response location are determining the results. The most plausible explanation remains to be in terms of hemisphere-related factors.

G.   Experiment 16

1.   Introduction

The purpose of Experiment 16 was to test an additional hypothesis concerning the role of finger position as a factor determining the observed visual field effects. It was hypothesized that relative left-right finger position within the hand might be important. For the right hand the index finger is leftmost and the middle finger is rightmost; the reverse is true for the left hand. This is true as long as the fingers are positioned perpendicular to the body, regardless of whether the hand is central or lateral. It was possible that the visual field effects were a function of compatibility between the stimulus type and the relationship between the stimulus visual field (left or right) and the finger position within the hand (left or right).

For example, for left hand responses using RA1 there is compatibility between middle finger mismatch responses (which are made on the leftmost of the two fingers being used) and mismatch pairs appearing in the right visual field, whose lateral position "mismatches" that of the responding finger. For left hand responses using RA1, there is also compatibility between match responses made on the index finger (rightmost) and match pairs in the right visual field. This sort of compatibility could account for the advantage for the visual field contralateral to the responding hand seen with RA1. Extending this logic, the same type of compatibility could explain the effects seen with RA2.

The major manipulation in Experiment 16 was to eliminate the left-right position of the fingers by placing the response board such that it was parallel to the horizontal axis of the display and of the body. In this case, the middle finger is slightly nearer to the display, than is the index finger but neither is to the left or right of the other. If the compatability effects described above have been operative, this positioning of the response

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board should eliminate those effects.

2. Method

Experimental Design. The design was identical to that used in Experiment 15.

Procedure. The procedure was identical to that used in Experiment 15, with the following exception. The response board was placed in a central position but with the response keys parallel to the horizontal axis of the display and to the body.

3. Results

For each subject, the median reaction time and percentage of error were computed for each stimulus type by visual field by responding hand condition, collapsing over trial blocks and eliminating the first practice block. These data are shown in Figures 13 and 14. Individual subject data are in Appendix F.

Two separate ANOVAs were performed, each excluding center visual field data to focus on left-right differences. To allow comparison with Experiments 13 and 15, one analysis was done for subjects using RA1, and a second analysis was done for subjects using RA2. Each of these analyses included hand order as a between-subjects factor, and visual field, stimulus type and responding hand as within-subjects factors. The results of each ANOVA are discussed below.

Response Assignment 1. The only main effect approaching significance was a tendency for the right hand (514 msec) to be faster than the left hand (545 msec, $F(1,10) = 4.82$, $p < 0.06$). There was a significant interaction between hand and hand order ($F(1,10) = 18.34$, $p < 0.01$), the faster hand being that used during the second session.

There was a significant interaction between responding hand and visual field ($F(1,10) = 5.66$, $p < 0.05$), and a tendency for the responding hand by visual field by stimulus type interaction also to be significant ($F(1,10) = 3.32$, $p < 0.10$). T-tests of the interaction scores indicate that there was a significant advantage for the stimulus in the visual field contralateral to the responding hand for mismatches ($t(1,11) = 3.39$, $p < 0.01$), but not for matches. For matches there tended to be a left visual field advantage for

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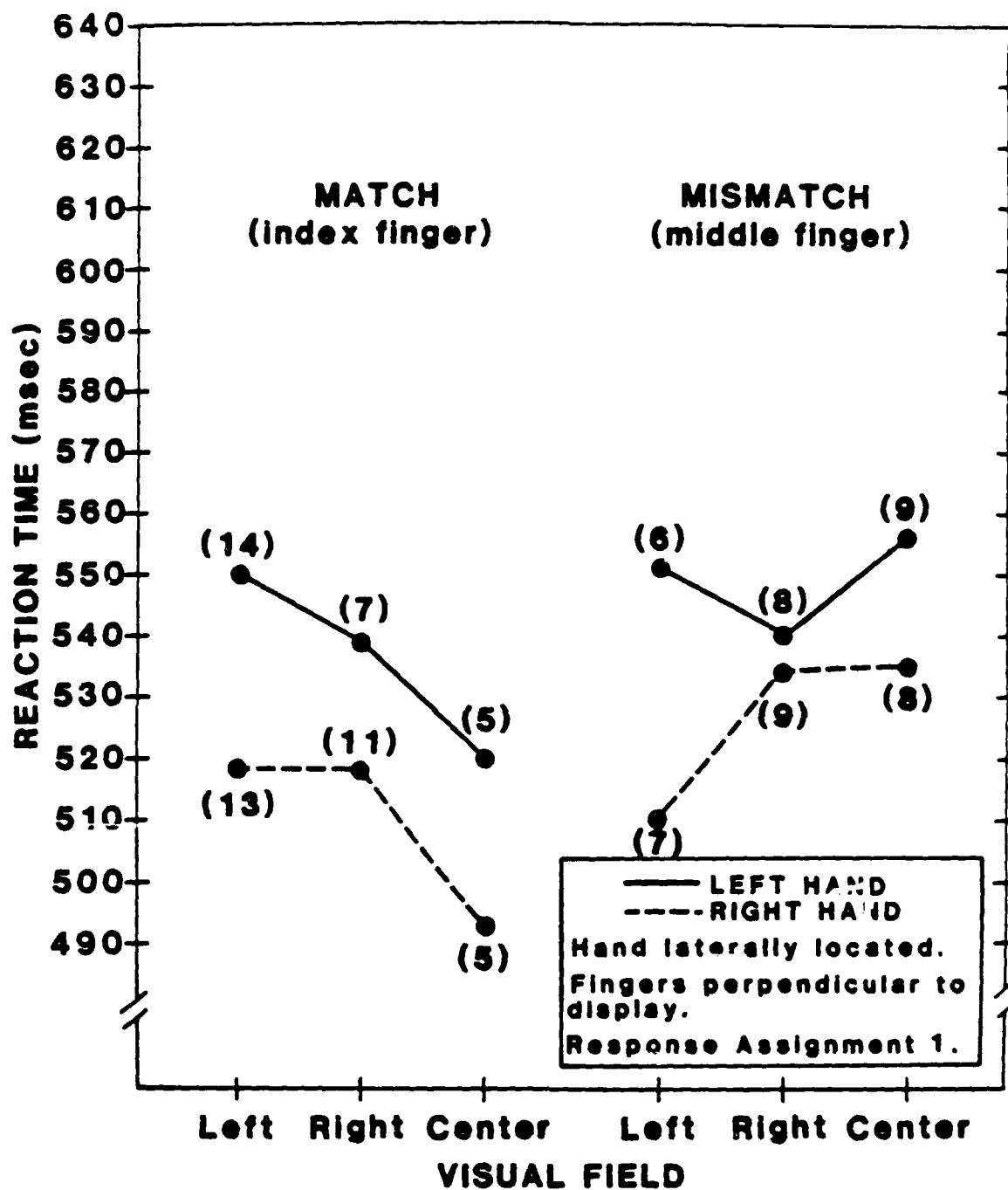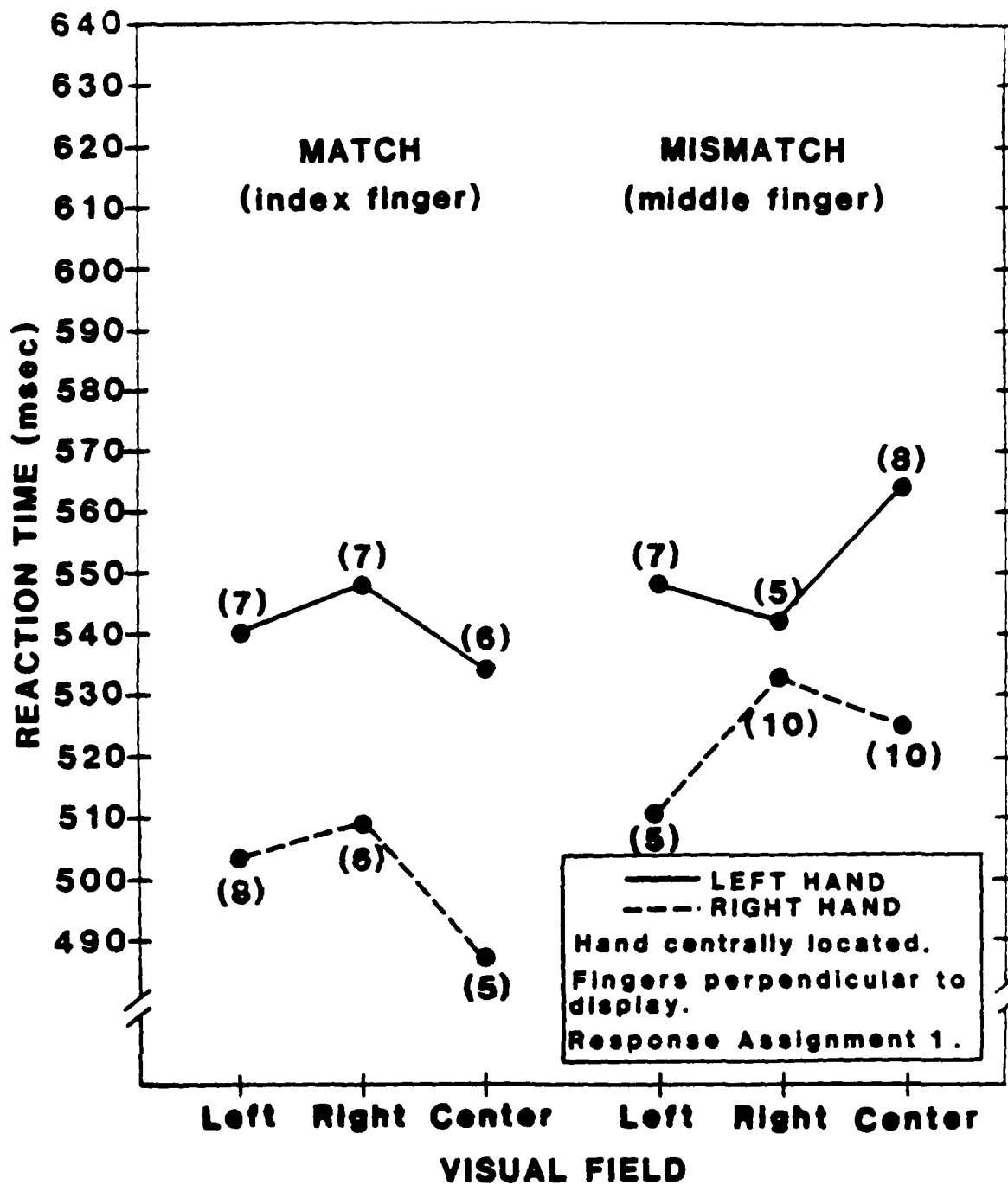Figure 13. Major Results of Experiment 16 For Response Assignment 1.
Percentage of error is in parenthesis.
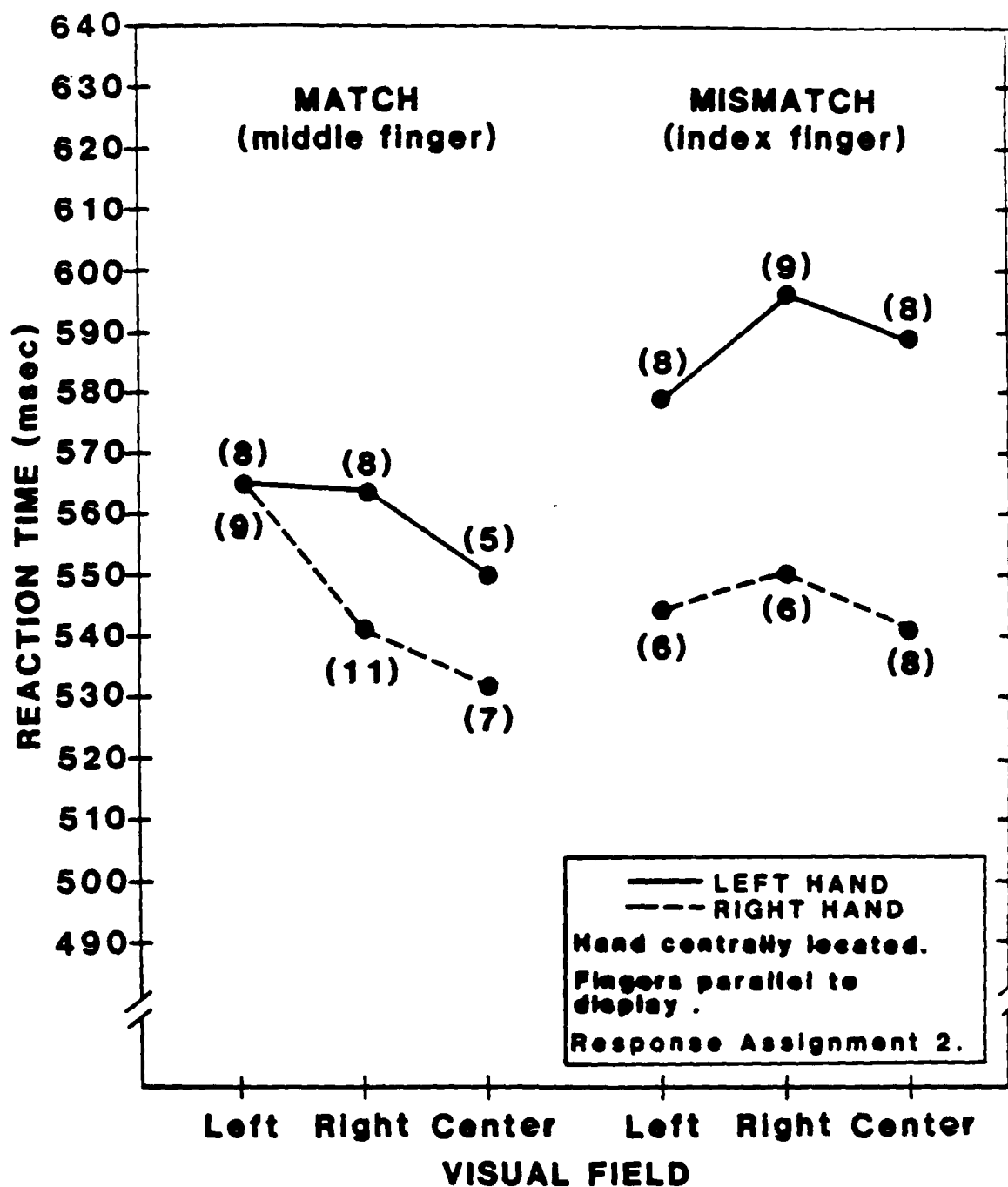
Figure 14. Major Results of Experiment 16 For Response Assignment 2.
Percentage of error is in parenthesis.

either hand; 10/12 subjects showed this trend for left hand performance and 8/12 for right hand performance.

The ANOVA on the arcsine transformation of percentage of error indicated that only the responding hand by visual field by stimulus type interaction was significant ($F(1,10)$ = 19.54, $p < 0.01$). The most important aspect of this is that for mismatches the error scores are consistent with the reaction time scores in suggesting that performance is better for stimuli appearing in the visual field contralateral to the responding hand. Percentage of error for matches shows less evidence of a responding hand by visual field interaction. There is no evidence of a speed-accuracy tradeoff.

Response Assignment 2. The only effects significant at the five percent level were the effects of hand order and the interaction between hand order and hand. Subjects who used their right hand first were faster (503 msec) than those who used their left hand first (623 msec, $F(1,10)$ = 5.51, $p < 0.05$). Subjects were faster with the hand used during the second session ($F(1,10)$ = 30.35, $p < 0.01$).

The hand by visual field interaction only approached significance ($F(1,10)$ = 3.29, $p < 0.10$). As can be seen in Figure 10, right (but not left) hand matches favor the visual field ipsilateral to the responding hand and left (but less so right) hand mismatches show a similar trend. T-tests indicated that the interaction score was not reliable for either stimulus type, although it approached reliability for matches ($t(1,11)$ = 1.55, $p < 0.10$).

An ANOVA of the arcsine transformation of the percentage of error indicated that only the interaction between hand and hand order was significant ($F(1,10)$ = 7.16, $p < 0.02$). When the right hand was used first, the right hand had slightly less error (7.0%) than did the left hand (7.7%). However when the left hand was used first, the left hand had considerably less error (7.4%) than did the right hand (8.2%). These tendencies suggest that, in terms of accuracy, performance was less efficient with the hand used second; this pattern is opposite from that implied by the reaction time data. This suggests that hand order effects were subject to speed-accuracy tradeoffs, with performance being faster, but less accurate, for the hand used second. There was, however, no evidence of systematic speed-accuracy tradeoffs affecting the conditions of major interest. The lower error rate

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for right hand, left visual field matches (see Figure 14) is not a reliable effect.

4. Discussion

The major purpose of Experiment 16 was to determine whether the hand by visual field interactions observed in Experiment 13 were replicated when the hand was repositioned to eliminate certain possible stimulus-response compatibility effects. For RA1, the results of Experiments 13 and 16 are highly similar. A comparison of Figures 5 and 13 indicates similar responding hand by visual field by stimulus type interactions. For each experiment, there tends to be an advantage for stimuli in the visual field contralateral to the responding hand for mismatches, but not for matches. The contralateral visual field advantage is consistent with the occurrence of intrahemispheric interference.

Thus, performance using RA1 tends to replicate that seen in Experiment 13, thus weakening the idea that compatibility effects related to finger position are important. The results involving RA2 (see Figures 7 and 14) also question this idea, although the replication of effects is less striking. In particular, the interaction between responding hand and visual field which was rather pronounced in Experiment 13B only approaches significance in Experiment 16, although it is similar in nature. In both experiments there is a tendency for responses to favor stimuli in the visual field ipsilateral to the responding hand when RA2 is used.

In general, therefore, the results of Experiment 16 do not support the idea that compatibility effects related to finger position are determining the observed responding hand by visual field interactions.

There are some differences between Experiments 13 and 16 that merit some comment. For both response assignments, and particularly for RA1, two major differences are, first, that reaction times are slower in Experiment 16, and second, that match responses are faster than mismatch responses in Experiment 13 but not in Experiment 16. The differences between these two experiments are very similar to those seen in comparing Experiments 13 and 15. It appears that repositioning the hand either laterally (rather than centrally) or with fingers parallel (rather than perpendicular) to the display increases response time. When this occurs, the difference between match and mismatch reaction

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times is eliminated. This is rather intriguing, implying an interaction between response-related and more central, decision-related factors.

H. Experiment 17

1. Introduction

In Experiment 17, a lexical decision task was used to examine the effects of intrahemispheric interference. A major rationale was to examine the effects of interference on a task for which the left hemisphere is specialized. The majority of the studies conducted in this research program to date have involved tasks for which a right hemisphere advantage has been reported (Cohen, 1972; Geffen, Bradshaw & Wallace, 1971), although the present results question whether this is a reliable effect. The lexical decision task requires subjects to decide whether a letter string comprises a word (e.g., BOAT) or a nonword (e.g., TOAB). A right visual field, left hemisphere advantage has frequently been reported for this task (e.g., Bradshaw & Gates, 1978), and is consistent with left hemisphere superiority at linguistic skills.

Another rationale for switching from the capital letter-matching task was to decrease the effects of several factors characterizing this task which might mask effects of intrahemispheric interference. One of these factors was the necessity to make "match-mismatch" decisions. There is considerable evidence that match and mismatch decisions may be products of different processing operations (Bamber, 1969; Krueger, 1979), and that there may be hemispheric differences in the relative efficiency of each hemisphere for these operations. Several studies have reported a right hemisphere advantage for match decisions and a left hemisphere advantage for mismatch decisions (Egeth & Epstein, 1972), although this interaction is not always reliably replicated. Effects of this interaction could, in part, be responsible for the variability in effects associated with match and mismatch responses seen in the present research.

The capital letter-matching task is also vulnerable to effects of variation in processing strategy. It is not a heavily lateralized task and does not produce a reliable visual field advantage. It is likely that subjects can use either a left or right hemisphere stimulus processing

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strategy. However, if there are individual differences in strategy flexibility and/or consistency, then this would add variability to the data which might mask interference effects. A task requiring a more consistent strategy, such as the lexical decision task, is less vulnerable to masking of effects by such variation.

2. Method

Stimuli. The lexical decision task that was selected required subjects to decide whether a letter string comprised a word or nonword. Since item length, word frequency, and word grammatical class have been suggested as affecting the reliability of the right visual field advantage (Bradshaw & Gates, 1978; Day, 1977; Fredericksen & Kroll, 1970; Leiber, 1976), it was desirable to control for these factors. For word items, it was decided to use four-letter, one-syllable nouns since these characteristics have been associated with reliable effects. Also, the item length is adequately short such that it is likely that the item is perceived as a unit. It was decided to systematically manipulate word concreteness, since this is another factor that has been reported to affect the right visual field advantage (Day, 1977). Half of the words were concrete nouns and half were abstract.

Existing word lists rating concreteness-abstractness (e.g., Paivio, Yuille, & Madigan, 1968) did not include sufficient numbers of four-letter nouns for the purposes of Experiment 17. Therefore, a brief study was conducted to obtain concreteness ratings of a list of 223 nouns taken from Thorndike and Lorge (1944). The method and results of this study are described in Appendix G. Both the between- and the within-subject ratings that were obtained had reliabilities exceeding 0.90. Also, there was high reliability between the ratings in the present study and those of Paivio, et al. The 64 nouns having the highest concreteness rating and the 64 having the lowest concreteness ratings were selected for use as stimulus items.

Nonwords were created by taking each word item and recombining its letters to create a one-syllable, pronounceable nonword. Homophones of real words were not used. Appendix H lists the 64 abstract words, 64 concrete words, and 128 nonwords made from each of the words, also indicating the average frequency ratings.

The stimulus list was divided into four blocks of 64 trials each. Each

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block consisted of 16 of the concrete words, 16 of the abstract words of similar frequency, and the 32 nonwords formed from the letters of each word. Half of each item type was designated for presentation in the right visual field stimuli and half of similar frequency was designated for the left visual field. Both item type and item visual field were randomly ordered within a trial block.

There were also two practice trial blocks, each thirty-two items in length and composed similarly to the test trial blocks described previously. The practice blocks did not use any of the items in the test blocks.

Each item was presented in either a vertical or horizontal orientation, with orientation being consistent for a given subject. It was decided to systematically manipulate this factor between subjects because, although it seems logical that the left hemisphere advantage should be more reliable with the more linguistically natural horizontal orientation, the vertical orientation has often been recommended to reduce the effects of left-to-right visual scanning biases (Bryden, 1982). It is difficult to see how such scanning biases can affect performance in conditions in which the brevity of stimulus presentation is insufficient for eye movements to occur. Nonetheless, it was decided to systematically manipulate stimulus orientation to examine whether reliable differences occurred.

Each letter measured 5.0 mm by 5.0 mm. For the vertical orientation, the inner edge of the most central letter was 18.0 mm from the fixation point. There was 1.5 mm between the bottom of one letter and the top of the one below it. Two letters appeared above the horizontal axis through the fixation point, and two appeared below this axis. In the vertical orientation, each letter appeared between 2.06 and 2.63 degrees of visual angle.

For the horizontal orientation, the inner edge of the most central letter (in either visual field) was 13.0 mm from the fixation point. There was 1.0 mm between letters. The letters were vertically positioned on the horizontal axis through the fixation point. Since subjects viewed from a distance 500.0 mm from the display, the four-letter item appeared between 1.49 to 4.12 degrees of visual angle. In the horizontal condition, it was decided to allow a smaller visual angle from the fixation point to the inner-most letter in order to reduce the information viewed in more lateral, peripheral vision, where acuity is poorer. Hemispheric projections are, however, easily obtained

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for information presented at least one degree from visual fixation.

Subjects. The subjects were thirty-two right-handed males from the same population used for the previous experiments.

Apparatus. The apparatus used previously was used here.

Experimental Design. Subjects were tested in two test sessions, each lasting approximately one hour and occurring on two successive days. Subjects used the right hand in one test session and the left hand in the other, with hand order counterbalanced across subjects. Within each hand order group, half of the subjects used Response Assignment 1 (RA1) (index finger keypress for "word", middle finger keypress for "nonword"), and half used Response Assignment 2 (RA2), the reverse of RA1. Within each of these groups, half of the subjects were exposed to the vertical stimulus orientation, and half were exposed to the horizontal orientation.

Within each test session, each subject was presented with two practice blocks (32 trials each) and four test blocks (64 trials each). The blocks were composed as described previously. Although the stimuli were identical for the two test sessions, the test blocks were presented in a different random order for each session.

Procedure. The procedure was similar to that used in the previous experiments. Each trial block proceeded as follows. A small fixation plus appeared in the center of the screen. The subject was instructed to carefully fixate on the plus, and when fixated to press both response keys to initiate the trial. The fixation plus remained on, but 500 msec later a stimulus item appeared for 150 msec in the left or right visual field. The stimulus was immediately followed by a 150 msec mask. The mask consisted of four square patches, one overlaying each of the areas in which a stimulus letter had appeared. Each patch looked like a very dense array of fine, bright dots and was created by lighting all of the CRT pixels in the area over each letter. The fixation plus disappeared with the offset of the mask.

The subject's task was to judge whether each item was a word or a nonword, and to indicate the decision with an appropriate keypress using either RA1 or RA2 as designated by instruction. Following the response, performance feedback (either the correct reaction time or the word "ERROR") appeared for one second in the center of the screen above the former location

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of the plus. The plus then reappeared signalling the beginning of a new trial.

One difference from the previous experiments was the necessity for additional procedures for controlling subject error rate. Pilot work indicated that there was a greater frequency of high error rates (exceeding twenty percent) than had occurred in previous experiments. Since reaction time was the dependent measure, high error rates are problematic because they increase the probability of speed-accuracy tradeoffs and correct guessing.

During pilot testing, stimulus size, form, and positioning were manipulated to optimize perceptual clarity. Stimulus duration could not, however, be increased without decreasing the probability of obtaining the hemispheric projections necessary for the research. It is worthwhile to note that response confusion (i.e., pressing the wrong key) was reported as a major source of error as it had been in earlier studies.

It was decided to control error rate by use of several procedures. First, in the initial contact, subjects were informed that their eligibility for the second test session depended on having a sufficiently low error rate. Second, the required error rate was relaxed to allow up to twenty percent errors. This rate has, in fact, been reported in a number of visual half-field studies using the lexical decision task (Day, 1979; Bradshaw & Gates, 1978). After each test block subjects were encouraged to lower their error rate if it had exceeded twenty percent for that block. Third, subjects having average error rates exceeding twenty percent in the first session were not asked to return for the second session. The data from omitted subjects was, however, retained for a separate analysis.

3. Results

Because a relatively high error rate had been allowed, each subject's data were carefully scrutinized for a possible speed-accuracy tradeoff. This was done by comparing the median left and right visual field reaction time for each session, and determining whether the performance advantage inferred from this was consistent with that implied by comparison of average percentage of error for the left and right visual field. If the percentage of error differed by ten percent between the visual fields and suggested that performance

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was better in the visual field associated with the slower median reaction time, then occurrence of a speed-accuracy tradeoff was inferred. None of the subjects met this criterion.

For each subject the median reaction time was computed for each stimulus type (concrete word, abstract word, nonword) by visual field by responding hand condition, collapsing over the four test blocks. The corresponding average percentage of error was also calculated. Individual subject data are contained in Appendix I. Analyses of variance (ANOVA) were done on median reaction time and percentage of error using stimulus type, visual field, and responding hand as within-subjects variables and presentation orientation, response assignment, and hand order as between-subjects variables.

For reaction time there was a main effect of hand ($F(1,24) = 4.93$, $p < 0.05$), with the left hand (844 msec) being faster than the right hand (941 msec). This effect is in dramatic contrast with the tendency in all previous experiments for the right hand to be faster than the left and will be discussed more fully later.

There were also main effects of stimulus type ($F(2,48) = 49.83$, $p < 0.01$) and of visual field ($F(1,24) = 29.74$, $p < 0.01$). Reaction time was similar for abstract words (841 msec) and for concrete words (823 msec), but was longer for nonwords (1013 msec). Reaction time was faster for right visual field stimuli (867 msec) than for left visual field stimuli (918 msec).

Of greatest interest for present purposes are interactions involving the factors of responding hand (H), visual field (V), stimulus type (T), and Response Assignment (R). There was a significant four-way interaction between these factors (RHTV, $F(2,48) = 4.57$, p. < 0.05) that is shown in Figure 15. An additional analysis was done to determine the reliability of the visual field simple effects involved in this interaction. Asterisks indicate significant visual field simple effects in Figure 15, and the corresponding statistics are included in Table 11. There is a tendency for the right visual field advantage to be most reliable for the abstract word condition, but otherwise there is no discernable pattern of interest in the simple effects.

There was also a significant four-way interaction between responding hand, visual field, stimulus type, and hand order ($F(2,48) = 5.11$, $p < 0.01$). Asterisks indicate significant visual field simple effects in Figure 16 (see
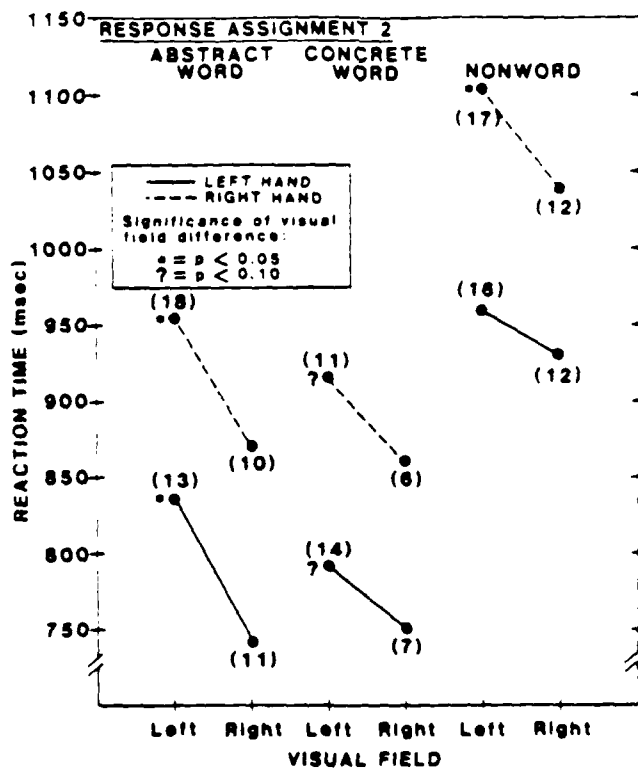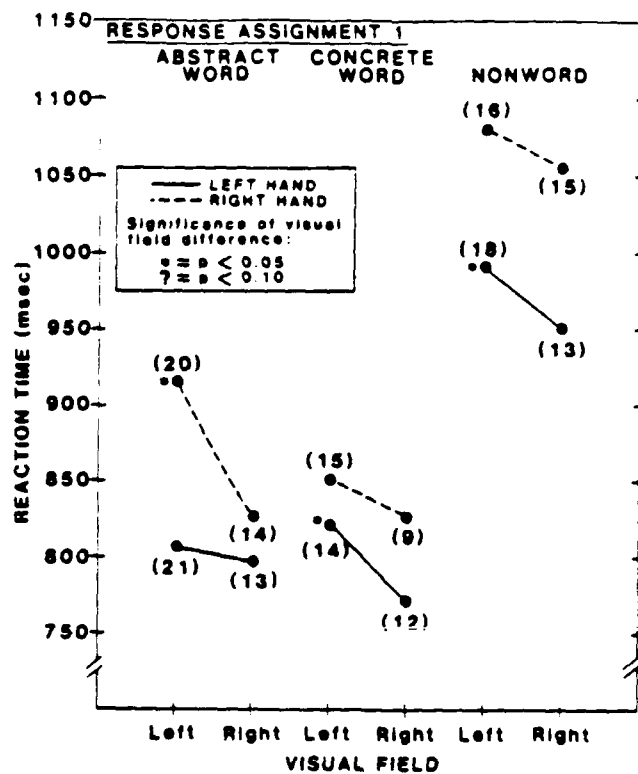
Figure 15. Experiment 17 Interaction Between Response Assignment, Stimulus
Type, Visual Field, and Responding Hand. Percentage of error
is in parenthesis.

TABLE 11

Experiment 17: Reliability of Visual Field Simple
Effects in Response Assignment by Hand by
Stimulus Type by Visual Field Interaction.

RA	Hand	Condition Stimulus Type	F-value	Degree of Freedom	Probability
1	Left	Concrete Word	6.09	1,12	< 0.05
1	Left	Nonword	4.91	1,12	< 0.05
1	Right	Abstract Word	10.37	1,12	< 0.01
2	Left	Abstract Word	27.05	1,12	< 0.01
2	Left	Concrete Word	4.23	1,12	< 0.10
2	Right	Abstract Word	7.05	1,12	< 0.05
2	Right	Nonword	13.83	1,12	< 0.01
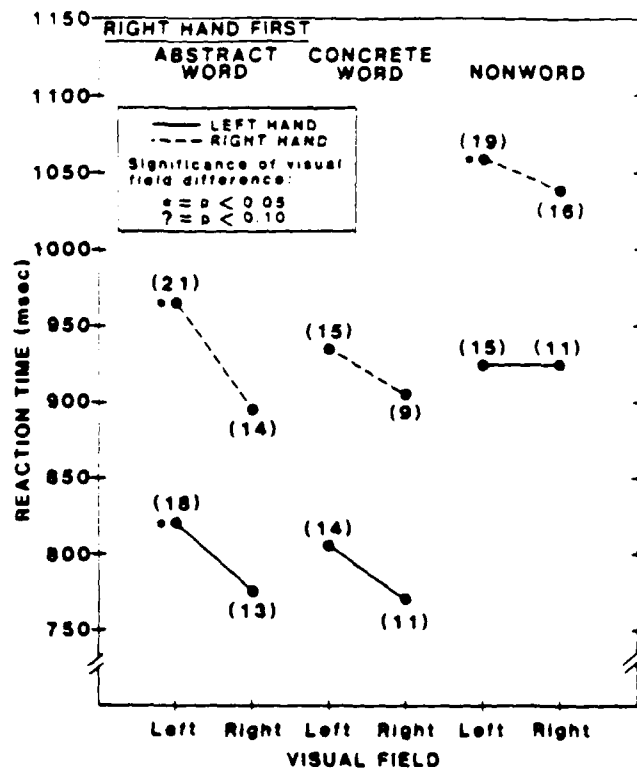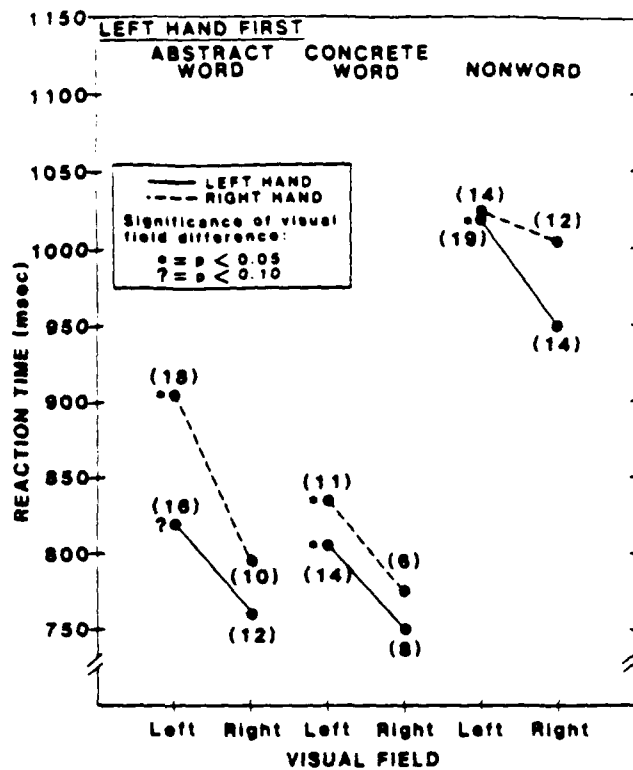
Figure 16. Experiment 17 Interaction Between Hand Order, Stimulus Type, Visual Field, and Responding Hand. Percentage of error is in parenthesis.

Table 12 for statistics). The right visual field advantage was more reliable in the hand order in which the left hand went first. It is notable that for right hand performance during the first session, the right visual field advantage was significant only for abstract words, while for left hand performance during the first session, the right visual field advantage is highly significant for both concrete words and nonwords, and approaches significance for abstract words.

Some additional attention was paid to identifying the conditions in which the previously mentioned overall left hand advantage occurred. Figure 15 suggests that the left hand advantage was more reliable for RA2 than for RA1. Indeed, although the response assignment by hand interaction did not approach significance ($p > 0.10$), 13/16 subjects using RA2, but only 9/16 using RA1, had a left hand advantage. Figure 16 suggests that a major source of the overall left hand advantage was the relatively slow performance by the right hand when used during the first session. Among subjects using their right hand first, 13/16 showed a right hand disadvantage, while only 9/16 of those using their left hand during the first session showed a right hand disadvantage. An additional notable feature of Figure 16 is that when first session (i.e., unpracticed) performance by the left and right hands are compared, left-hand reaction time is considerably faster, particularly for word items, even though all subjects were strongly right-handed.

There were a number of interactions whose significance requires that they be mentioned even though they are much less theoretically relevant. These interactions involved the between-subjects variables and stimulus type. They are listed in Table 13. Table 14 shows the reaction times for the highest level of these interactions (Presentation Orientation by Response Assignment by Hand Order by Stimulus Type, $F(2,48) = 3.57$, $p < 0.05$). The pattern of the lower level interactions can be deduced from this one. The pattern of this interaction suggests that for the horizontal orientation and RA1, subjects were faster for the hand order in which the right hand was used first, with this difference being greater for nonwords. This pattern was also true for the vertical orientation and RA2, although the hand order differences are somewhat smaller.

However, for the horizontal orientation and RA2, subjects were faster when the left hand was used first, and this difference was greater for words

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TABLE 12

Experiment 17: Reliability of Visual Field Simple
Effects in Hand Order by Hand by Stimulus
Type by Visual Field Interaction.

Hand Order	Hand	Stimulus Type	F-value	Degrees of Freedom	Probability
Left first	Left	Abstract Word	3.64	1,12	< 0.10
Left first	Left	Concrete Word	8.58	1,12	< 0.01
Left first	Left	Nonword	8.68	1,12	< 0.01
Left first	Right	Abstract Word	8.81	1,12	< 0.01
Left first	Right	Concrete Word	7.14	1,12	< 0.02
Right first	Left	Abstract Word	7.12	1,12	< 0.02
Right first	Right	Abstract Word	8.64	1,12	< 0.01
Right first	Right	Nonword	12.96	1,12	< 0.01

TABLE 13

Experiment 17: Significant Interactions Involving
Presentation Orientation (P), Response Assignment (R),
Hand Order (O), and Stimulus Type (T).
Reaction time in msec.

Interaction	F Value	Degrees of Freedom	Probability
PT	5.02	2,48	< 0.05
PRO	8.44	1,24	< 0.01
POT	4.31	2,48	< 0.01
PROT	3.57	2,48	< 0.05

TABLE 14

Experiment 17: Interaction Between Presentation Orientation,
Response Assignment, Hand Order, and Stimulus Type.
Reaction time in msec.

Presentation Orientation →	Horizontal						Vertical					
Response Assignment →	1			2			1			2		
Stimulus Type →	Abs	Con	NW	Abs	Con	NW	Abs	Con	NW	Abs	Con	NW
Hand Order ↓												
Left first	991	934	1191	735	706	875	700	698	833	850	826	1104
Right first	737	749	792	1011	988	1061	907	887	1252	799	799	995

than nonwords. For the vertical orientation and RAl, subjects were also faster when the left hand was used first, but this effect was greatest for nonwords.

The results of the ANOVA of an arcsine transformation of percentage of error indicated main effects of stimulus type ($F(2,48) = 14.75$, $p < 0.01$) and visual field ($F(1,24) = 17.17$, $p < 0.01$). Percentage of error was less for concrete words (10.9) than for abstract words (15.2) or nonwords (14.9). Percentage of error was also less for the right visual field (11.2) than for the left visual field (16.1).

There was a significant hand by hand order interaction ($F(1,24) = 10.84$, $p < 0.01$). Percentage of error did not vary for the left hand as a function of use during the first session (13.8) or the second session (13.8). However, the right hand percentage of error was less when used during the second session (11.9) than the first (15.4).

There were also significant interactions between stimulus orientation and visual field ($F(1,24) = 13.75$, $p < 0.01$) and between these two factors and stimulus type ($F(2,48) = 4.19$, $p < 0.05$). The error rates corresponding to the latter interaction are shown in Table 15. In general, there was a greater difference between the visual field error rates for the horizontal orientation, but this was especially true for abstract words.

There were significant interactions between presentation orientation, stimulus type, and hand ($F(2,48) = 3.14$, $p < .05$) and between these factors and response assignment and hand order ($F(2,48) = 3.63$, $p < .05$). The percentage of error corresponding to the latter interaction is shown in Table 16. Interactions involving the hand factor are of some interest because they suggest whether a speed-accuracy tradeoff might be contributing to the overall left hand reaction time advantage. There was no difference between overall left hand and right hand error rates, which were both 13.7 percent. If a percentage of error difference exceeding two percent is used as the criterion, comparison of left and right hand error performance for the conditions in Table 16 indicates that left hand error rate was higher for seven of the comparisons, right hand error rate was higher for six comparisons, and the hand difference error rate was less than two percent for eleven comparisons. This supports the idea that left and right hand error rates were not different, and that there was not a speed-accuracy tradeoff.

TABLE 15

Experiment 17: Error Rates Corresponding to the Presentation
Orientation by Visual Field by Stimulus Type Interaction.

Stimulus Type T	Abstract		Concrete		Nonword	
Visual Field T	Left	Right	Left	Right	Left	Right
Presentation Orientation L						
Horizontal	21.8	8.7	15.7	7.3	19.0	13.1
Vertical	14.8	15.3	10.8	9.9	14.7	12.8

TABLE 16

Experiment 17: Error Rates Corresponding to the Interaction Between
Presentation Orientation, Stimulus Type, Hand,
Response Assignment, and Hand Order.

Presentation Orientation T		Horizontal						Vertical					
Response Assignment T		1			2			1			2		
Stimulus Type T		Ab	Con	NW	Ab	Con	NW	Ab	Con	NW	Ab	Con	NW
Hand Order L	Hand L												
Left First	Left	12.9	13.3	17.6	10.2	9.4	21.7	19.6	10.2	13.5	12.9	10.6	13.5
	Right	15.0	10.2	14.8	15.6	9.4	14.8	14.5	8.6	8.0	11.7	5.5	14.8
Right First	Left	19.9	17.6	18.0	13.3	10.6	7.4	16.4	10.2	10.7	12.5	11.7	14.7
	Right	20.7	12.9	19.7	14.5	9.0	14.3	17.2	16.4	20.5	16.0	9.8	14.5

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There was also a significant interaction between hand, hand order, visual field, and stimulus type ($F(2,48) = 4.29$, $p < 0.05$). The error rates corresponding to this interaction are shown in Figure 16. The pattern of the interaction is not meaningful for the present purposes, except that it does suggest that a speed-accuracy tradeoff cannot account for the left hand reaction time advantage.

Analysis of Omitted Subjects. One problematic feature of use of the lexical decision task was the tendency for subject error rates to be relatively high. The criterion for discontinuing testing of a given subject was described earlier. Using this criterion, eighteen subjects were omitted. The individual subject data are included in Appendix J.

The frequency of omitted subjects in each treatment group is shown in Table 17. One notable feature of these data is the tendency for more subjects who used their right hand to be omitted. This is consistent with the idea that right hand responses were more difficult, a tendency suggested by the slower right hand reaction time for non-omitted subjects. Second, there is a tendency for subjects using Response Assignment 2 (word = middle finger keypress, nonword = index finger keypress) to be omitted more frequently. Inspection of Appendix J indicates that RA2 was associated with longer reaction time. This is consistent with the idea that RA2 is more difficult than RA1, a tendency seen in the reaction time data of earlier experiments, although not in the analysis of Experiment 17 subjects having error rates below twenty percent.

Table 18 shows the means of the median reaction times for omitted subjects for each visual field by responding hand by stimulus type condition. The twelve subjects who used their right hand tended to have faster reaction times than the six who used their left hand, although the error rates are similar. This is a trend that is opposite from that seen among non-omitted subjects. Omitted and non-omitted subjects are similar, however, in that performance is more efficient for right visual field stimuli. T-tests were done comparing visual field reaction times for all omitted subjects. There was a significant right visual field advantage for abstract words ($t(17) = 3.53$, $p < 0.01$) and for nonwords ($t(17) = 3.16$, $p < 0.01$). The difference was not significant for concrete words.

TABLE 17

Experiment 17: Frequency of Omitted Subjects in Each Between-Subjects Condition.

Response Assignment	Presentation	Responding Hand		Total
		Left	Right	
1	Horizontal	0	3	6
	Vertical	1	2	
2	Horizontal	4	1	12
	Vertical	1	6	
	Total =	6	12	

TABLE 18

Experiment 17: Means for Omitted Subjects.

Stimulus Type →	Abstract				Concrete				Nonword			
Visual Field →	LVF		RVF		LVF		RVF		LVF		RVF	
Measure →	RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err
Hand ↓												
Left (N=6)	1205	39	1070	21	1114	36	1086	18	1426	30	1297	27
Right (N=12)	885	31	810	24	858	29	790	21	1085	32	1010	24

4. Discussion

The purpose of Experiment 17 was to examine whether the effects of intrahemispheric interference could be observed in performance of a task for which the left hemisphere is specialized. The three findings most relevant to this issue are first, the presence of an overall right visual field advantage, second, the absence of an interaction between responding hand and visual field and third, the presence of an overall left hand reaction time advantage.

The highly reliable right visual field advantage is consistent with the idea that the left hemisphere of right-handed individuals is more efficient at linguistic processing such as that required by the lexical decision task. This finding is important for validating the operationalization of the lexical decision task used in Experiment 17 as one for which the left hemisphere is specialized.

In previous experiments, the presence of intrahemispheric interference has been inferred by a responding hand by visual field interaction such that response is slower when the stimulus is projected to the hemisphere controlling the response. Either an advantage for the visual field contralateral to the responding hand, or a reduction in the right visual field advantage when the right hand was used, would be consistent with this type of interaction. Neither of these was, however, observed in Experiment 17. Response was consistently faster for right visual field stimuli, regardless of responding hand. In other words, the advantage of the left hemisphere over the right for stimulus processing did not vary as a function of whether the left hemisphere did or did not direct the response. Thus, the type of evidence used to infer intrahemispheric interference in previous experiments is not present in Experiment 17.

Of great relevance, however, to the issue of whether performance of a left hemisphere task is affected by intrahemispheric interference is the presence of a left hand advantage. The advantage of the left hand over the right could occur because the left hemisphere is more occupied by lexical decision-making, and thus is less efficient at directing the response, and, the right hemisphere, which directs the left hand, is relatively unoccupied with lexical decision-making, thus allowing it to be more efficient at directing the response. In other words, one interpretation of the left hand advantage is that it reflects effects of intrahemispheric interference,

although in a way different from that in previous experiments.

Several aspects of the data support this idea. One supportive pattern is the tendency in earlier experiments for there to be a right hand advantage, if a reliable hand advantage occurred (e.g., as in Experiments 13A, 15A, and 16). These experiments involved the physical identity letter matching task for which a left visual field-right hemisphere advantage has been reported (Cohen, 1972; Geffen, Bradshaw, & Wallace, 1971). The left visual field advantage was not replicated in the present experiments. However, the tendency toward a right hand advantage could reflect the fact that the right hemisphere was, in fact, more involved than the left hemisphere in the letter-matching processing, thus reducing right hemisphere efficiency at directing response making. This would result in left hand response being slower than right hand response.

Thus, there tends to be a left hemisphere-right hand advantage in conditions perhaps more dependent on right hemisphere stimulus processing, but a right hemisphere-left hand advantage in performance of a task heavily dependent on the left hemisphere for stimulus processing. Both of these patterns are consistent with the idea that there is interference with response making within the hemisphere more involved with stimulus processing and decision-making.

Also consistent with the idea that the left hand advantage is related to intrahemispheric interference are some hints in the data that the left hand advantage was more pronounced in more difficult conditions. The left hand advantage is more pronounced for first test session performance, when subjects were relatively less practiced at the task. Also, the left hand advantage is more pronounced for subjects using Response Assignment 2, which may be more difficult than Response Assignment 1. Although no overall difference between response assignment conditions was observed in Experiment 17, the fact that more omitted subjects used Response Assignment 2, and the results of previous experiments, suggest that this condition is more difficult.

Thus, although the evidence is of a type different from that in earlier experiments, the results of Experiment 17 indicate that interference between stimulus and response processing activities associated with the same hemisphere can reduce the efficiency of performance of a task heavily dependent on left hemisphere capabilities. The results extend the range of tasks whose

performance efficiency may be affected by intrahemispheric interference. Furthermore, the results indicate that intrahemispheric interference may result in left hand performance being more efficient that right hand performance, even for strongly right-handed individuals. This idea will receive further discussion.

Of less relevance to the issue of intrahemispheric interference, but of some general interest are results related to effects of stimulus orientation and stimulus type. Stimulus orientation, either horizontal or vertical, had no effect on the magnitude of the right visual field advantage. The fact that this advantage was not greater for the horizontal orientation argues against the idea that left-to-right scanning biases may be responsible for a right visual advantage when the stimulus orientation is horizontal (Bryden, 1982). If such scanning biases were operative, then the right visual field advantage should have been larger for the horizontal orientation since both scanning bias and hemispheric specialization favored the right visual field. The results suggest that either orientation can be used in visual half-field studies of hemispheric capabilities as long as sufficient attention is paid to insuring that subjects are centrally fixated. The vertical orientation may, however, be preferred because it allows the stimulus to be presented in retinal areas of greater peripheral acuity.

Also of note was the reliability of the left hemisphere-right visual field advantage across all three stimulus types. Although the right visual field advantage was larger for abstract words (72 msec right visual field advantage) than for concrete words (43 msec) or nonwords (38 msec), there was no significant variation between these. The right visual field advantage for nonwords in the lexical decision task is consistent with other studies involving right-handed subjects (Bradshaw, Gates, & Nettleton, 1977; Bradshaw & Gates, 1978) and testifies to the heavy involvement of the left hemisphere in this task. It is interesting to note that in a study which included both right- and left-handed subjects (Leiber, 1976), a right visual field advantage was observed for words, but not nonwords. This suggests less consistent left hemisphere involvement for this sample. This may reflect mainly the performance of the left-handers, for whom there is evidence of reduced language lateralization (Herron, 1980). Leiber (1976), however, does not separately analyze the performance of the two handedness groups.

The consistency of the right visual field advantage for both concrete and abstract words questions the assertion that although the left hemisphere is superior in recognizing abstract words, the hemispheres are equally efficient in recognizing concrete nouns (Day, 1977). The present results are consistent with other results (Bradshaw & Gates, 1978) suggesting that the left hemisphere is superior for recognition of either word type.

In conclusion, the results of Experiment 17 provide additional evidence of left hemisphere specialization for lexical decision making. More importantly for present purposes, the results indicate that such processing can interfere with response-making directed by the left hemisphere such that response is more efficient when directed by the less occupied right hemisphere. This results in an advantage for left-hand performance by right-handed subjects.

I. Summary

The conclusions regarding Experiments 13 through 17 are summarized here, with more detailed discussion of the theoretical and applied implications contained in Section VI. Experiments 13 through 17 are important in a variety of respects. First of all, Experiments 13, 15, and 16 establish the reliability of the effect of response assignment on performance. The subtle variation in response assignment used in the research was not anticipated to cause significant variation in the patterns of performance, yet the results clearly indicate that such variation can occur. Whether such variation occurs appears to be task-specific. The results suggest that both of the observed effects associated with the two response assignments are likely to be related to brain hemisphere functioning, rather than to stimulus-response compatibility effects.

Given the effect of response assignment it was important to determine that the elimination of intrahemispheric interference observed in the earlier go-no go studies was not associated only with a particular response assignment. The results of Experiment 14 indicate that evidence of interference is reliably eliminated when the go-no go response is used, regardless of response assignment. This lends additional support to the idea that the occurrence of intrahemispheric interference is related to the level of response processing demand.

Finally, Experiment 17 extends the generalizability of interference effects across tasks, indicating that such effects impact performance of a linguistic task for which the left hemisphere is specialized. The results indicate, however, that the impact upon performance can vary in form, causing visual field differences in some tasks (e.g., letter-shape matching) and hand differences in other tasks (e.g., lexical decision-making). A particularly important finding was that interference can cause right-handed subjects to be more efficient with left hand, rather than right hand, response. The implications of this will receive further discussion.

SECTION V
ANALYSIS OF INDIVIDUAL DIFFERENCES

A. Introduction

Of considerable interest in the research has been the nature and effect of individual differences upon performance. These issues have become of increasing concern because of 1) observation of between-individual variation even for performance of relatively simple tasks such as those used in the present research, and 2) increasing evidence in the literature that there are individual differences in brain organization which are associated with significant differences in the quality of performance. More specifically, there is evidence that the degree to which language-related functions are lateralized in the left hemisphere can affect the quality of language-related processing and the level of vulnerability to intrahemispheric interference. Several studies have suggested that individuals who have more bilateral representation of language functions may be more vulnerable to effects of intrahemispheric interference (Heister, 1984; Sussman, 1982). Since the frequency of bilaterally-represented language is greater among left-handers (Herron, 1980), one might predict a greater frequency or magnitude of interference among those who tend to be less right-handed.

Analysis of individual differences focused on data collected in Experiments 13 and 17. Both of these studies had similar response conditions, each involving a centrally-located, two-choice response using either Response Assignment 1 or 2. The two studies differed in stimulus processing demands, Experiment 13 requiring letter-shape matching and Experiment 17 requiring lexical decision-making. Of interest was whether the nature of the individual differences varied with differing stimulus processing demands.

The analysis of each experiment addressed three questions. First, do individuals differ in whether their performance is reliably affected by intrahemispheric interference? This question was addressed by examining for individuals, the reliability of the differences used to infer interference effects. The second question was, is the magnitude of interference related to other subject characteristics? As was mentioned earlier, there is some evidence that degree of right-handedness may be related to the degree of

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interference, with greater interference for less right-handed subjects. If so, there should be a negative correlation between the handedness score and the degree of interference. It should be recognized, however, that the present data cannot provide a strong test of this relationship, given the strong right-handedness of all the subjects.

The relationship between magnitude of interference and overall performance speed was also examined. Of particular interest was whether the slowest subjects also showed the greatest interference.

The final question was, in a given task, are the different, possible indices of intrahemispheric interference related? Although the measures most strongly reflecting interference were different for the letter-shape matching and lexical decision-making tasks, the relationship of the value of the nonsignificant measure to the significant one is of interest. On the one hand, one might predict a negative relationship, if it is hypothesized that interference is manifested in specific effects. For example, if interference influences one aspect of performance (e.g., visual field differences), it might not affect another (e.g., hand differences). The data tend, in general, to support this idea. On the other hand, a positive relationship is possible if interference has strong specific effects, but also more generalized effects on performance. For example, interference within a given task might be most strongly reflected in visual field differences, but also in a tendency for there to be hand differences. The discussion of Experiment 17 indicated that, when considering group data, this tends to be true for the letter-shape matching tasks. There are visual field differences indicative of interference, but also a tendency toward a right hand advantage.

B. Analysis of Experiment 13A

Table 19 indicates the data that were considered in the analysis. To compute the measures of interference magnitude, data were included only for subjects using Response Assignment 1 and for mismatch responses, conditions which are most reliably associated with intrahemispheric interference. However, to compute overall reaction time all Response Assignment 1 data were included, including center visual field data and match data.

To address the question concerning whether there are individual differences in the reliability of the interference effect, significance tests were performed on the differences between left and right visual field reaction

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TABLE 19

Experiment 13A: Data Relevant to Individual Differences.

Reaction time (msec) is based on median.

Subject	Handedness Score [1]	Overall RT [2]	Interference Reflected in VF RT Differences [3]			Interference Reflected In Hand RT Differences		
			L Hand (RVF-LVF)	R Hand (LVF-RVF)	Total (L + R Hand)	L Hand RT [4]	R Hand RT [4]	L - R
5	57	524	2	66*	68	518	538	-20
12	55	487	9?	14	23	539	472	67
7	54	477	18	40*	58	558	443	115
4	53	471	38*	-47?	-9	470	459	11
1	52	419	35*	12	47	428	436	-8
11	52	472	83*	-13	70	497	420	77
6	51	542	52*	53*	105	540	585	-45
10	49	491	87	32*	119	564	462	102
3	48	421	18	-29*	-11	420	432	-12
2	45	547	17	39?	56	530	569	-39
8	44	511	13	-14	-1	554	471	83
9	44	467	29	26	55	494	483	11

1 Maximum score is 60; higher scores indicate greater right hand dominance.

2 RT = reaction time; overall RT is based on all data.

3 Based on mismatch data only, left and right visual field.

4 Based on all data.

* VF difference has $p < 0.05$.

? VF difference has $p < 0.10$.

times for each hand. Table 19 indicates the magnitude of those differences (based on medians) for each subject, with positive values indicating a difference favoring the visual field contralateral to the responding hand, which is consistent with intrahemispheric interference. It should be noted that the majority of the values are positive, which is consistent with the significant hand by visual field interaction in this experiment.

It was somewhat difficult to determine the best approach for doing the significance tests. There have been some attempts to develop significance tests for individual subject data, but these have applied mainly to accuracy data rather than to reaction time data. The approach selected in the present case was to perform t-tests comparing left and right visual field reaction times.

Although visual field was a within-subjects factor, it was not possible to perform a dependent mean t-test because incorrect trials made unequal the number of trials for each visual field condition. Dependent mean t-tests generally require equal data point frequencies for the conditions being compared. It was therefore decided to do a t-test for independent means. Use of this test provided a very conservative test of the reliability of the mean differences, since covariance between conditions could not be subtracted. To counterbalance this conservatism, differences likely to occur less than ten percent of the time by chance alone were considered somewhat reliable and of interest.

The visual field differences that were found to be reliable are indicated in Table 19. The majority of the subjects (10/12) show a reliable difference (p < 0.10) for response by at least one of their hands. However, for most of the subjects for whom there is reliable interference, it affects responses by only one of their hands; of the nine subjects who showed reliable interference, four showed interference only with the use of the left hand, three showed interference only with use of the right hand, and two showed reliable interference for both hands. It is interesting that, for a right-handed sample, interference is likely to affect performance of one hand, which can be either the right or left, but less often performance of both.

As indicated in Table 19, two subjects showed evidence that performance was reliably faster for the visual field ipsilateral to the responding hand. It is interesting that both of these subjects showed this pattern when using

their right hand, and that it did not generalize to affecting left hand performance. All of the left hand differences that were reliable were consistent with effects of intrahemispheric interference.

Thus, the individual differences revealed by this analysis are mainly related to whether interference will affect performance when the right or the left hand is used. It is interesting to note that the subjects who showed interference when the left hand was used tended to have relatively high right-handedness scores. Subjects who showed interference during right hand performance showed a greater range of handedness scores.

The second question of interest concerned whether the magnitude of the interference was related to subject characteristics such as overall reaction time or degree of right-handedness. The previous discussion indicates there was some tendency for subjects having high handedness scores to be the ones who showed reliable interference when using the left hand. To further examine the relationship between interference magnitude and handedness, an interference score was computed for each subject by summing the interference magnitudes for the left and right hand. Using the Pearson Product-Moment Correlation, the correlation was computed between the total interference scores and the handedness scores. The correlation coefficient was 0.12.

A significant negative correlation would support the idea that less right-handed individuals are more vulnerable to interference. The computed correlation obviously does not support this hypothesis. However, this is not unexpected since the present sample includes only right-handed subjects. A stronger test would be provided by data from a sample including a wider range of handedness scores, particularly those of left-handed subjects.

A correlation was also computed between total interference scores and the overall reaction times. The correlation coefficient was 0.41, which was not significant. Thus, there appears to be little relationship between overall performance speed and interference magnitude.

The third question concerned whether different possible indices of intrahemispheric interference were related. Of interest here was whether there was a relationship between the interference score based on visual field differences, the primary evidence of interference in Experiment 13A, and the interference score based on overall hand reaction time differences. This

latter type of score was the primary evidence of interference in the lexical decision task. Discussion of Experiment 17 suggested that the tendency toward a right hand-left hemisphere response advantage is consistent with intrahemispheric interference in letter-shape matching tasks, which have been described as being more heavily dependent on the right hemisphere for stimulus processing.

To examine the relationship between the two measures, the overall left and right hand reaction times were compared, and the right hand advantage computed (see Table 19). The correlation between the interference scores based on visual field differences and those representing the right hand advantage was 0.04.

The absence of a correlation between measures suggests that in the letter-shape matching task, the effects of intrahemispheric interference upon the performance of an individual subject may be relatively specific. For a given individual, such effects may be manifested either in a visual field advantage or in a responding hand advantage, but not usually in both. The fact that, in general, visual field effects rather than hand differences tend to be significant in overall analyses indicates that intrahemispheric interference is more likely to affect visual field differences in letter-shape matching tasks.

In summary, the analysis of Experiment 13A indicates the following. First, there is variation between individuals in the nature and reliability of effects of intrahemispheric interference. While, in the present sample, most of the individuals showed effects of interference upon visual field differences, such effects generally occurred for a given subject during either left or right hand responding, but not during both. Also, while interference was manifested for most subjects in terms of visual field differences, there were some subjects for whom interference appeared to more strongly affect overall hand reaction time differences.

Second, there is little evidence of a relationship between interference magnitude and handedness score or overall speed of performance. Examination of these relationships was, however, limited by the uniformity in handedness scores and the small sample size.

Finally, there appears to be little relationship between the two indi-

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cators of interference. There is some evidence that, for a given subject, interference causes visual field differences or hand differences, but not both.

C. Analysis of Experiment 17

Table 20 indicates the data that were considered in the analysis. Subjects are ordered by handedness score, ranging from high to low. The measure of intrahemispheric interference for each subject is the reaction time advantage of the left hand over the right. Since this advantage did not vary with response assignment or stimulus type, all of the data were included in computing the left and right hand reaction time, and the overall reaction time.

To address the question of whether there are individual differences in the reliability of the interference, tests were performed comparing the left and right hand reaction times, using the approach described earlier. Of the thirty-two subjects in Experiment 17, twenty-two showed a reliable hand advantage. Of these, fourteen individuals showed a reliable left hand advantage, consistent with the overall group pattern, but eight individuals showed a reliable right hand advantage.

An important question is whether this variation reflects true individual differences or effects due to different individuals having different hand orders. Table 21 indicates the frequency of subjects who showed a reliable left or right hand advantage or no advantage for each hand order condition. One point to note is that within either hand order condition there is a tendency for there to be a greater frequency of reliable hand advantages favoring the second hand used. For example, for the left hand first order, there is a greater frequency of reliable right than left hand advantages, meaning the right hand was faster. This makes sense in that the right (second) hand benefits from practice in doing the task.

A more important point, however, is that within each hand order there still exist individual differences. Within each hand order five (about one-third) of the subjects did not show a reliable hand advantage (i.e., they showed no reliable evidence of interference). Within each group there is also at least one subject whose reaction time favored the hand used first. Of special note is the fact that for the group who used the left hand first, four

TABLE 20

Experiment 17: Data Relevant to Individual Differences.
Reaction time (msec) is based on median.

Subject	Handedness Score[1]	Overall RT[2]	L Hand RT[2]	R Hand RT	R - L
12	59	1388	1356	1419	64*
25	57	686	726	647	79*
15	56	880	1020	741	279*
18	55	1068	973	1163	190*
22	55	689	584	794	210*
2	54	1042	879	1206	327*
19	54	618	614	622	8
32	54	1073	885	1261	376*
3	53	1429	1003	1854	851*
6	53	953	970	935	35
30	53	831	789	873	84*
4	52	609	604	614	10
10	52	921	898	945	47
31	52	897	941	852	89
16	51	1122	1158	1086	72?
17	51	1395	1049	1741	692*
23	51	711	739	684	55*
24	51	863	857	869	12
26	51	1120	1125	1114	11
27	51	830	849	812	37*
28	51	774	651	898	247*
29	51	670	601	740	139*
1	50	797	883	711	172*
8	50	649	676	621	55*
7	49	813	776	851	75
9	49	747	680	814	134*
13	48	745	723	767	44

TABLE 20 (Concluded)

Experiment 17: Data Relevant to Individual Differences.
Reaction time (msec) is based on median.

Subject	Handedness Score[1]	Overall RT^2	L Hand RT^2	R Hand RT	R - L
20	48	919	1043	794	249*
11	47	899	757	1041	284*
14	47	915	804	1026	222*
5	43	834	746	922	176*
21	41	676	655	698	43

[1] Maximum score is 60; higher scores indicate greater righ   dominance.

[2] RT = reaction time; overall RT is based on all data.

* Hand difference has p <0.05.

TABLE 21

Frequency of Subjects Showing a Reliable Hand
Advantage for Each Hand Order.

Reliable Hand Advantage → Hand Order ↓	Right Hand	Left Hand	None
Left Hand First	7	4	5
Right Hand First	1	10	5
Total →	8	14	10

subjects showed a reliable left hand advantage, even though this hand did not benefit from practice at doing the task.

The analysis suggests the following hypothesis for describing the individual differences in the intrahemispheric interference shown in the performance of this task. One dimension of individual differences is whether or not an individual shows reliable interference, as evidenced by a reliable left hand advantage. A second dimension has to do with the magnitude of the interference effect relative to practice effects. For example, one hypothesis explaining the distribution of frequencies for subjects who used their left hand first is that each subject's performance reflects a combination of interference effects and practice effects. It could be argued that subjects who showed a left hand advantage showed larger interference effects relative to practice effects, subjects who showed a right hand advantage had larger practice effects relative to interference effects, and those who showed no hand difference experienced equal practice and interference effects.

Thus, analysis of data from Experiment 17 also suggests that there are individual differences in interference magnitude, although description of these differences is made somewhat difficult by the presence of hand order effects. The analysis of the relation between overall reaction and interference magnitude sheds some further light on one factor related to these differences. The correlation between overall reaction time and interference magnitude was significant ($r(30) = 0.54$, $p < 0.05$), indicating that as interference magnitude increased, so did overall reaction time. It was the slowest subjects who showed the greatest intrahemispheric interference. It may be that interference resulted in not only a left hand advantage, but also in a general slowing of response time.

There was, however, no relationship between handedness score and interference magnitude ($r(30) = 0.001$). As was pointed out earlier, examination of this relationship may be limited by the fact that all subjects were strongly right-handed.

Since the visual field differences provided no evidence of interference, the relationship between the two possible measures of interference was not examined for Experiment 17.

D. Summary

The analyses of data from Experiment 13 and Experiment 17 provide evidence of individual differences in the magnitude of interference. Individual differences in the letter-matching task of Experiment 13 were expressed in terms of whether the contralateral visual field advantage indicative of interference was more evident during left or right hand performance. Individual differences in the lexical decision task of Experiment 17 were more evident in terms of differences in interference magnitude, (i.e., the magnitude of the left hand advantage). The magnitude of this advantage was related to overall reaction time.

This last finding is of special interest because it suggests that it may be especially important to identify individuals who experience large magnitudes of intrahemipheric interference. For those individuals, performance in general may be slow, so it is particularly important to facilitate performance by designating left hand response.

It is important to note that the analyses that were conducted are somewhat preliminary and limited. This is because individual differences did not become a major focus until relatively late in the research. Also, analysis was limited by the availability of appropriate statistics and methodology. However, even the present analysis revealed interesting differences, and suggests that further analysis has great potential for contributing to personnel selection and individualized training procedures. This issue will be discussed further in Section VI.

SECTION VI
GENERAL DISCUSSION AND CONCLUSIONS

A. Theoretical Implications of the Research

The fundamental question of the research concerns how the organization and resources of the brain hemispheres affect the quality of performance, and how understanding of these characteristics can be used to improve performance, particularly in the stressful, information-overload conditions frequently faced by military operators. Of specific interest was the effect of interactions between activities associated with the same hemisphere, particularly interactions which degrade performance.

A major conclusion of the research is that there may be intrahemispheric interference between information processing activities which degrades performance in certain conditions requiring rapid performance. Such interference affects a variety of tasks, including those for which there is no reliable evidence of hemispheric specialization (e.g., letter shape matching) and those for which there is reliable evidence of hemispheric specialization (e.g., lexical decision-making).

A question of major interest concerns the specific ways in which such interference affects performance. The results of the current research concur with those of earlier studies indicating that there are varying effects. The present results suggest that the nature of task stimulus processing demands may help determine how intrahemispheric interference is manifested and, in particular, whether visual field differences or responding hand differences are observed.

When the task involves making match-mismatch decisions about stimuli (i.e., are two stimuli the same or different?), intrahemispheric interference causes response to be slower for stimuli initially received by the hemisphere controlling the response. In operational terms, subjects are slower for stimuli appearing in the visual field ipsilateral to the identity of the responding hand (e.g., for right visual field stimuli when a right hand response is being used). In other words, in matching tasks, intrahemispheric interference determines whether subjects are faster for right or left visual field stimuli.

For the lexical decision task, however, intrahemispheric interference is manifested in a different way. In this task, intrahemispheric interference influences which responding hand is slower, rather than which visual field is slower. For this task, there was a consistent right visual field advantage indicative of left hemisphere linguistic superiority. However, right hand responses were slower than left hand responses, even though subjects were right-handed. The involvement of the left hemisphere in lexical decision-making degraded the efficiency with which it could direct response, relative to right hemisphere efficiency in directing response.

One issue of concern is the capability to predict how intrahemispheric interference may affect performance for a given task. The present results provide one suggestion. Intrahemispheric interference was manifest in terms of stimulus visual field, but not hand differences, for stimulus matching tasks in which the superiority of one hemisphere over the other is less consistent. For example, as has been pointed out previously, there are several reports of a right hemisphere superiority for letter-shape matching (Cohen, 1972; Geffen, Bradshaw, & Wallace, 1971), yet this superiority is not reliably replicated. In contrast, intrahemispheric interference was manifested in terms of a right-left hand difference for the lexical decision task, one which reliably produces evidence of left hemisphere linguistic superiority. It therefore seems worthwhile to propose that intrahemispheric interference is more likely to result in visual field differences in tasks for which there is less consistent superiority of one hemisphere, but is more likely to result in hand differences in tasks for which the superiority of one hemisphere is highly reliable.

Also of major interest is the identification of factors determining first, when intrahemispheric interference is likely to occur and, second, the magnitude of such interference. It was originally hypothesized that the level of processing demands of particular processing activities might determine the magnitude of intrahemispheric interference, with interference decreasing as processing demand decreased and increasing as processing demand increased. The processing demand of a particular activity, specifically stimulus processing and response processing, was inferred in a relative sense by consideration of the relative difficulty of that activity and overall reaction time.

The studies involving the letter-shape matching task systematically manipulated stimulus and response processing demand and, thus, provided the best evidence concerning the effects of these factors. The results point to the conclusion that more central, resource-related decision and response factors determine the magnitude of intrahemispheric interference, while factors related to early perceptual processes (e.g., stimulus recognition) have relatively little importance. In conditions in which evidence of intrahemispheric interference was observed, the magnitude of the interference did not change with manipulations designed to either decrease perceptual demands (e.g., elimination of the stimulus mask as in Experiment 2) or to increase perceptual demands (e.g., increasing stimulus visual angle as in Experiment 10).

In contrast, changes in response-related demands had a major impact upon interference magnitude. Intrahemispheric interference does not appear to affect performance when performance requires a unimanual go-no go response, i.e., when only a single response made by one finger is possible and subjects must discriminate the stimuli for which that response is appropriate. When the go-no go response was used in the matching task, performance varied neither as a function of visual field nor responding hand. This pattern was highly reliable, appearing in a variety of matching tasks. There was, unfortunately, insufficient time to examine whether use of the go-no go response in the lexical decision task also eliminated evidence of interference. However, the data of Day (1977), who required subjects to use a go-no go response in a lexical decision task, suggest an absence of interference.

Evidence of intrahemispheric interference appears more reliably when the task requires a unimanual choice response, i.e., when certain stimuli signal response by one finger, while others signal response by a different finger within the same hand. There was reliable evidence of interference in all of the two-choice matching tasks involving Response Assignment 1 (an index finger keypress indicates match, and a middle finger keypress indicates mismatch) and in the two-choice lexical decision task. The fact that the unimanual choice response is more difficult than the go-no go response supports the hypothesis that interference magnitude is related to level of response demands.

However, the results obtained when Response Assignment 2 (the reverse of Response Assignment 1) was used require qualification of this hypothesis. Response Assignment 2 was associated with slower reaction time in the matching tasks and higher error rate in the lexical decision task, suggesting it was more difficult than Response Assignment 1. The reason for this is unclear at this time. Since the motor demands of the two response assignments are identical, the difference must be related to more central aspects of response organization associated with translating a decision into a motor response. The difference may be related to a recoding advantage for translating the more positive decision (match or word) into an index finger response, and the more negative decision (mismatch or nonword) into a middle finger response, rather than vice versa. Nevertheless, given the apparent greater difficulty of Response Assignment 2, the previous hypothesis would lead to a prediction that intrahemispheric interference should be greater for Response Assignment 2 than for Response Assignment 1.

The evidence for this is mixed. For the matching tasks, the evidence is clearly not supportive. Use of Response Assignment 2 resulted in an advantage for the visual field ipsilateral (rather than contralateral) to the responding hand. The results of Experiments 15 and 16 rule out non-hemisphere-related explanations of this effect in terms of stimulus-response compatibility effects. The best explanation at this time is that the ipsilateral visual field advantage reflects intrahemispheric facilitation between stimulus and response activities associated with the same hemisphere. The results therefore suggest that in matching tasks, increased response difficulty may increase overall reaction time, but also result in intrahemisphere facilitation, rather than increases in interference.

Performance of the lexical decision task is, however, somewhat supportive of a relationship between increases in response difficulty and in intra-hemispheric interference. Although there was no overall difference in reaction time between the two response assignments, this may be because subjects who initially had very poor performance (i.e., very high error rates) were omitted from further testing. The fact that the frequency of being omitted was much greater for subjects initially tested with Response Assignment 2 supports the idea that this response assignment was more difficult. Among subjects who did complete testing, there was a greater

frequency of evidence of intrahemispheric interference, i.e., of a left hand advantage, among subjects who used Response Assignment 2. This provides some support for a relationship between increases in response difficulty and interference.

The present results suggest that it is the difficulty of more central, resource-demanding aspects of responding (e.g., response organization) that are critical in determining interference, rather than aspects associated with the actual motor movement. Even though reaction time was slower in conditions which seemed to change the motor quality of the task (e.g., when the hand was placed in a lateral, rather than a central position), the critical effects did not change with these manipulations. The critical effects did, however, vary with the nature of processes associated with translating the decision regarding the stimulus into a particular response. These processes are likely to be more central, and to occur relatively earlier during response-making.

The reason for the difference between tasks in the effects of increased response difficulty can only be speculated upon at this time. It may be related to the fact that the hemispheres are more equally capable at performing the stimulus processing required by the matching tasks, while the left hemisphere is significantly superior at lexical decision-making. For the lexical decision task, stimulus processing must rely heavily on the left hemisphere, reducing left hemisphere resources for directing right hand response, an effect which increases with greater response difficulty. However, for the matching tasks, greater hemispheric equivalence for stimulus processing may allow greater flexibility in processing strategy so that increases in response difficulty are not necessarily translated into increases in interference. The evidence of intrahemispheric facilitation suggests that increased response difficulty may result in beneficial activation effects within the hemisphere controlling the response.

A variety of evidence suggests that intrahemispheric interactions impacting performance are reduced, or at least do not differentially affect the two hemispheres, when overall task demands are relatively easy. First, in the matching tasks, there was either an absence of effects, or less reliable effects, for match responses, as compared to mismatch responses. There is both theoretical and empirical evidence suggesting that match decisions are less demanding than mismatch decisions. Second, use of the easier, go-no go

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response reliably eliminated evidence of intrahemispheric interference in tasks in which it had appeared. Third, performance of a letter recognition task (Experiment 9) reflected no hemisphere-related effects, but rather, seemed to be influenced by stimulus-response compatibility effects. Since letter recognition is highly practiced and relatively automatic, this task is easier than letter matching, an assumption reinforced by the faster reaction time associated with the letter recognition task. The absence of hemisphere-related effects for this task supports the idea that such effects are less likely in less demanding conditions.

The finding of evidence for intrahemispheric facilitation, while not expected in this research, is not without precedent. It should be noted that the effects which have been interpreted in terms of facilitation are similar in pattern to effects of interhemispheric transmission time, but have been interpreted as facilitation effects because they are much larger than those of transmission time (Bashore, 1981). A number of studies have reported evidence that activation within one hemisphere biases attention (Kinsbourne, 1970) and eye movements (Gur & Gur, 1977) toward the visual field contralateral to the activated hemisphere. Cotton, Tzeng, and Hardyck (1980) argued that response control by one hand might cause higher arousal in the hemisphere contralateral to the hand and thus bias attention toward the visual field contralateral to the more highly aroused hemisphere. This would result in an advantage for the visual field ipsilateral to the responding hand.

Such an attentional effects could explain the ipsilateral visual field advantage observed in the present studies. Alternately, the arousal could result in priming effects (Posner, 1978) causing the hemisphere controlling the response to be more efficient at stimulus processing, once stimulus information has arrived in that hemisphere. The present results cannot, however, distinguish between these two possible explanations of the facilitatory effect.

B. Applied Implications

The applied implications have relevance for task design, human-machine interface design, and other activities which require determining how stimulus and response-related characteristics can be selected to optimize performance. The analysis of individual differences has implications for personnel selection and training. For purposes of clarity, the implications

will be described in a fairly broad and definite manner. It is important to note, however, that they are inferences from basic research findings and require additional investigation before they validly can be applied to addressing real problems.

The results are most relevant for understanding and predicting performance in tasks which have the following characteristics: 1) critical stimuli appear briefly to the left or right of visual fixation, and 2) the required response is one that is heavily dependent on one brain hemisphere. The present research has involved a keypress response, for which there is considerable evidence of control by the hemisphere contralateral to the responding hand. However, the effects observed with use of manual finger response should theoretically generalize to other responses controlled mainly by one hemisphere. One important response which merits investigation is speech, which is very heavily dependent on the functioning of the left hemisphere in most individuals.

The results imply that, in tasks having these characteristics, the speed of performance may be affected by intrahemispheric interference, intrahemispheric facilitation, or stimulus-response compatibility. In the majority of the conditions in which hemisphere-related effects occurred, the lexical decision task excepted, these factors had larger effects on the relative speed of response to stimuli in the left versus the right visual field than on the relative speed of the two hands. Although the right hand tended to be faster than the left hand in the matching tasks, the larger effect on performance was the advantage for a particular visual field for a particular hand. Most of the applied implications are therefore described from the point of view of optimal positions for lateralizing stimulus presentation relative to response identity. The exception to this is the applied implication of lexical decision task performance, which has relevance for both hand and visual field selection.

In Table 22 are outlined the major implications of the present research with respect to specifying lateral locations for stimuli. Factors hypothesized to be important in determining the effects are indicated in parentheses; these factors merit further investigation.

The results imply that in tasks which require stimulus matching but which involve go-no go responses, assignment of the stimulus to a lateral visual

TABLE 22

Applied Implications of the Research.
See text for further explanation.

Stimulus Processing Characteristics	Response Processing Characteristics	Major Effect	Applied Implication
Stimulus matching (moderate central resource demand; weak hemispheric specialization)	Go-No Go Response (low central resource demand)	None	Stimulus presentation conditions can be determined by other factors.
Stimulus matching (moderate central resource demand; weak hemispheric specialization)	Choice Response (moderate central resource demand) "Easy" Response Assignment	IHI[1]	Present stimuli in the visual field contralateral to the responding hand.
	"Harder" Response Assignment	IHF[2]	Present stimuli in the visual field ipsilateral to the responding hand.
Lexical decision-making (moderate central resource demand; strong hemispheric specialization)	Choice Response (moderate central resource demand)	IHI[1]	Response should be controlled by the hand contralateral to the specialized hemisphere; present stimuli in the visual field ipsilateral to the specialized hemisphere.
Letter recognition (low central resource demand)	Choice Response (moderate central resource demand)	Finger position SRC[3]	Present stimuli in the lateral location congruent with that of the responding finger within the hand.

1 IHI = Intrahemispheric Interference
2 IHF = Intrahemispheric facilitation
3 SRC = Stimulus - response compatibility

field can be determined by factors other than hemisphere-related factors. It is also likely that stimulus-response spatial compatibility is not critical to consider in these conditions, although it may be important to examine this prediction when the go-no go response is laterally positioned. It seems likely that the requirement to make a choice between at least two responses in different lateral locations is necessary (though not sufficient) for evoking stimulus-response spatial compatibility effects.

The results clearly indicate that when a choice response is required, selection of stimulus location should include consideration of possible hemisphere-related and stimulus-response compatibility effects. In choice response tasks, hemisphere-related effects are more likely to impact performance when there are relatively high stimulus processing demands (e.g., stimulus matching or lexical decision-making). In stimulus matching tasks, either interfering or facilitatory intrahemispheric interactions can affect performance. The present results suggest that the former type of interaction is more likely when the translation from stimulus decision to response is relatively easy, while the latter is more likely when this translation is more difficult. This implies that for choice response assignments in stimulus matching tasks that involve relatively easy decision-response translation, critical stimuli should be presented in the visual field contralateral to the left-right identity of the responding hand. That is, if response by the left hand is required, performance will be faster if critical stimuli appear in the right, rather than the left visual field. For more difficult response assignments, critical stimuli should be presented in the visual field that is ipsilateral to the identity of the responding hand. That is for right hand responses, stimuli should appear in the right visual field. These principles appear to apply regardless of whether the hand is laterally or centrally located.

These principles, however, do not appear to apply to all tasks involving a choice response. They may not apply to tasks which involve stimulus processing for which one hemisphere is heavily specialized, such as lexical decision-making. In such tasks, performance will be fastest when stimuli appear in the visual field contralateral to the hemisphere specialized for stimulus processing (so that they are initially received by that hemisphere), and response is made by the hand controlled by the hemisphere not as heavily

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involved in stimulus processing. Thus, in verbal tasks, for which the left hemisphere is heavily specialized in most individuals, performance will be fastest when critical stimuli are presented in the right visual field, and responses are made by the left hand.

This last recommendation is particularly noteworthy because what is being suggested is that in some conditions, performance by the left hand may be faster than that by the right hand even for strongly right-handed subjects. The present results suggest this may occur for certain verbal tasks which place heavy demand on left hemisphere capabilities. This finding warns against the tendency, when making response assignments, to assume that right hand performance will be at least as efficient, if not more efficient, as left hand performance for right-handed individuals.

Finally, for unimanual choice response tasks involving relatively low stimulus processing demands (e.g., letter recognition, which is highly automatic), hemisphere-related effects may be minimal, but stimulus-response compatibility effects may require consideration. When unimanual choice responses are used in a central location, performance will be fastest when stimuli appear in the left-right location congruent with the left-right location of the responding finger within the hand. For example, if responses are made by the index and middle fingers of the left hand, stimuli requiring an index finger response should be presented in the right visual field and those requiring a middle finger response should be presented in the left visual field. Further investigation is required to determine whether such effects generalize to laterally-located unimanual choice responses.

The results also have implications for the relative quality of performance based on stimuli appearing in central versus lateral positions. Although not a major focus of interest, an intriguing pattern in the data was for match responses to be fastest for stimuli presented in the central visual field regardless of responding hand, but for mismatches responses to be fastest for stimuli appearing in either the left or right visual field, depending on the responding hand and response assignment. The data in Figure 5 illustrate this pattern. For match pairs, fastest reaction time is associated with the central visual field for either hand. However, for mismatch pairs, this is not the case. For the left hand, right visual field reaction time is fastest. For the right hand, the reverse is true.

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There are several possible explanations for this pattern. One hypothesis has to do with the relative goodness for detection of similarities versus differences of information perceived centrally (foveally) versus laterally (peripherally). Another hypothesis is that central presentation may, in general, be best, but not when significant hemisphere-related factors are influencing performance, as was the case with mismatches.

Regardless of the explanation, the applied implication is that central presentation of stimuli may not be optimal. Factors related to the nature of the processing that is performed for different stimulus types may determine if the central or lateral location is best.

The results also have a variety of other applied implications which are less clearly related to brain hemisphere capabilities, but which nevertheless deserve mention. One important implication is that task design should consider the effects of stimulus-response spatial compatibility even when responses are to be centrally rather than laterally located. Although central response location may eliminate effects of spatial compatibility associated with hand location, it does not necessarily eliminate effects of compatibility on the relative speed of the fingers within the hand. Experiment 9 clearly demonstrated such an effect, even for a task in which stimulus and response spatial location were irrelevant to determining the correct response.

Another implication is that, in conditions requiring choice responses, the manner in which the stimulus decisions are assigned to possible responses can affect overall response speed. In the present case, assigning the match decision to the index finger and the mismatch decision to the middle finger resulted in reaction time that was considerably faster than when the assignment was reversed. This effect was not anticipated, and has received little attention in existing literature. The applied recommendation is that, when choice responses are required, preliminary testing should be performed to determine the optimal decision-response configuration.

A final implication concerns the impact of hand position, central versus lateral, and hand orientation, either perpendicular or parallel to the body upon overall speed of performance. In the present studies, the fastest reaction times were obtained when the responding hand was centrally located with the fingers perpendicular to the body (e.g., Experiment 13). Either positioning the hands laterally (e.g., Experiment 15) or positioning the

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fingers parallel to the body (e.g., Experiment 16) slowed reaction time by 30 to 60 msec, particularly for the faster response assignment (Response Assignment 1). It is therefore recommended that manual responses be positioned centrally with fingers perpendicular to the body when that is possible.

The recommendations described previously are based on patterns seen in data averaged over groups of subjects. There will, however, clearly be variation in the validity of these principles for particular individuals. At this time it is not possible to predict individual differences in interference magnitude and, thus, the extent to which the performance of a given individual will be affected by failure to apply the described principles. At this time what is known is that there are individual differences in the magnitude of intrahemispheric interference and in the aspects of performance that are affected. This was clearest in performance of the letter-matching task in which there was variation in both when visual field differences were reliable and in whether interference was manifested also in terms of differences in overall hand speed. If additional research can identify measurable individual characteristics correlating with these differences, then they can be used to select personnel who experience minimal interference, or interference of a type that is less critical to performance. Alternately, individualized training procedures can be designed to aid those whose performance is heavily degraded by interference effects.

C. Recommendations for Future Research

As with any major research project, the present project suggests a multitude of areas in which further research could benefit the understanding of factors determining the quality of human performance. A variety of questions has been posed in this report. The present discussion will focus on three issues which have considerable potential for contributing to understanding human performance.

What are the effects of increases in central processing demands on the magnitude of hemisphere-related effects upon performance? The research has provided multiple pieces of evidence suggesting that the magnitude of central processing demands determines whether and how hemisphere-related factors will influence performance. The evidence has largely been based on the effects of various manipulations of response-related factors hypothesized to vary in

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central processing demand. There is a need, however, to validate this indirect evidence by examining the effects of direct manipulations of central processing demands. For example, one might require subjects to perform a simple memory task concurrent with the primary task, e.g., letter-shape matching. One could vary the size of the memory load to see how variations in central processing demands affect the magnitude of hemisphere-related effects. It was hoped that the present research would include this manipulation but the need to investigate effects of response assignment precluded such investigation.

Also of interest, particularly in terms of eventual application, is further investigation of the relationship between changes in central processing demand, type of task, and the nature of hemisphere-related effects. The completed research strongly suggests that changes in central processing demands can be manifested in different hemisphere-related effects for different tasks. It was hypothesized that increases in central processing demands from moderate to higher levels may result in increased intrahemispheric interference in tasks for which one hemisphere is specialized, but may result in intrahemispheric facilitation, rather than interference, in tasks for which neither hemisphere is specialized. This hypothesis is, however, speculative and merits further investigation.

How do individual differences in brain organization and activity affect performance? The present results clearly indicate that there are individual differences in the magnitude of intrahemispheric interference. The present research was not, however, designed to clarify the bases for these differences. There are, however, both empirical and theoretical bases for suggesting that individual differences in the manner in which language is represented in the two brain hemispheres may be related to the magnitude of intrahemispheric interference. More specifically, there is some evidence that interference may be greater for individuals in whom language is more bilaterally represented. In contrast to right-handers, in whom language is most frequently based in the left hemisphere, there is evidence that left-handers and females frequently have a more bilateral representation of language. There is also some evidence that performance by these groups more reliably reflects effects of intrahemisphere interference (Heister, 1984; Sussman, 1982).

One of the major recommendations of this report is that further efforts be devoted to the investigation of the effects of individual differences in brain organization and activity upon performance. An upcoming proposal by the present author will describe research aimed at investigating the relationship between the nature of an individual's language function representation in the brain and the vulnerability to brain-related interference effects between different aspects of task performance. The research will attempt to identify reliable indices of brain organization that can be used to predict the quality of an individual's performance in conditions in which there might be interference between different processing activities.

A second aspect of individual brain functioning which appears to be related to the quality of performance based on lateral stimuli is the relative arousal of the two brain hemispheres. It has been proposed that there are individual differences in the relative arousal of the two brain hemispheres, and that these differences are related to the magnitude of perceptual asymmetries as well as to other more global characteristics of individual personality and information processing style (Levy, Heller, Banich, & Burton, 1983). A recently begun project by the present author, and funded by the U.S. Army Research Institute, is investigating this hypothesis through the use of electroencephalography. This approach will also be proposed for use in investigating the influence upon performance of individual differences in language representation in the brain.

Investigation of factors determining stimulus-response spatial compatibility effects. The present research makes it clear that it is often difficult to disentangle brain hemisphere-related effects and stimulus-response spatial compatibility effects upon performance. This is, in part, because of the lack of understanding of the factors determining the different types of compatibility effects. Although there is a large literature discussing these effects, (e.g., Simon, Sly, & Vilapakkam, 1981; Wallace, 1971), the present research provokes several important questions which have not been addressed. The most important question is the following: what factors are necessary and sufficient for spatial compatibility effects to predominate in determining the quality of performance based on laterally-presented stimuli? The existing literature implies that lateral response location is a critical factor, yet the present research (i.e., Experiment 15)

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indicates that compatibility effects do not necessarily occur with lateral response locations. In contrast, certain types of compatibility effects occur even when the response is centrally located.

It is clear that both the location of the response and the type of task are important in determining compatibility effects. However, there is a need to clarify how variations in these factors affect the type and the magnitude of the spatial compatibility effect, and how these interact with hemisphere-related effects in visual half-field studies. There is increasing interest in these issues (see Cotton, Tzeng, & Hardyck, 1980; Heister, 1985), but little systematic research has been performed.

REFERENCES

Annett, M. and Annett, J. (1979) Individual differences in right and left reaction time. British Journal of Psychology, 70, 393-404.

Bamber, D. (1969) Reaction times and error rates for "sam- f-rent" judgments of multidimensional stimuli. Perception an physics, 6, 169-174.

Bashore, T. R. (1981) Vocal and manual reaction time estimates of inter hemispheric transmission time. Psychological Bulletin, 89, 352-368.

Berlucchi, G., Heron, W., Hyman, R., Rizzolati, G., and Umilta, C. (1971) Simple reaction times of ipsilateral and contralateral hand to lateralized visual stimuli. Brain, 94, 419-430.

Bowers, D., and Heilman, K. M. (1980) Pseudoneglect: Effects of hemispace on a tactile line bisection task. Neuropsychologia, 18, 491-498.

Bradshaw, J. L. and Gates, E. A. (1978) Visual field differences in verbal tasks: Effects of task familiarity and sex of subject. Brain and Language, 5, 166-187.

Bradshaw, J. L. and Nettleton, N. C. (1981) The nature of hemispheric specialization in man. The Behavioral and Brain Sciences, 4, 51-91.

Bradshaw, J. L. and Perriment, A. D. (1970) Laterality effects and choice reaction time in a unimanual two-finger task. Perception and Psychophysics, 7, 185-188.

Brinkman, J. and Kuypers, H. G. J. M. (1972) Split brain monkeys: cerebral control of ipsilateral and contralateral arm, hand, and finger movements. Science, 176, 536-539.

REFERENCES
(Continued)

Brown, W. P. and Ure, D. M. J. (1969) Five rated characteristics of 650 word association stimuli. British Journal of Psychology, 60, 233-49.

Bryden, (1982) Laterality: Functional Asymmentry in the Intact Brain. New York: Academic Press.

Cohen, G. (1972) Hemispheric differences in a letter classification task. Perception and Psychophysics, 11, 139-142.

Cotton, B., Tzeng, O. J. L., and Hardyck, C. (1980) Role of cerebral hemisphere processing in the visual half-field stimulus-response compatibility effect. Journal of Experimental Psychology: Human Perception and Performance, 6, 13-23.

Day, J. (1977) Right hemisphere language processing in normal right-handers. Journal of Experimental Psychology: Human Perception and Performance, 3, 518-28.

Day, J. (1979) Visual half-field word recognition as a function of syntactic class and imageability. Neuropsychologia, 17, 515-519.

Dimond, S. J. (1972) The Double Brain. London: Churchill-Livingston.

Egeth, H. and Epstein, J. (1972) Differential specialization of the cerebral hemispheres for the perception of sameness and difference. Perception and Psychophysica, 12, 218-220.

Fitts, P. M., and Seeger, C. M. (1953). S-R compatibility: Spatial characteristics of stimulus and response codes. Journal of Experimental Psychology, 46, 199-210.

REFERENCES
(Continued)

Frederiksen, J. R. and Kroll, J. F. (1976) Spelling and sounds: Approaches in the internal lexicon. Journal of Experimental Psychology: Human Perception and Performance, 2, 361-79.

Friedman, A. and Polson, M. C. (1981) The hemispheres as independent resources systems: Limited-capacity processing and cerebral specialization. Journal of Experimental Psychology: Human Perception and Performance, 7, 1031-1058.

Friedman, A., Polson, M. C., Dafoe, C. G. and Gaskill, S. J. (1982) Dividing attention within and between hemispheres: Testing a multiple resources approach to limited-capacity information processing. Journal of Experimental Psychology: Human Perception and Performance, 8, 625-650.

Geffen, G., Bradshaw, J. L. and Nettleton, N. C. (1972) Hemispheric asymmetry: Verbal and spatial encoding of visual stimuli. Journal of Experimental Psychology, 95, 25-31.

Geffen, G., Bradshaw, J. L. and Wallace, G. (1971) Interhemispheric effects on reaction time to verbal and nonverbal visual stimuli. Journal of Experimental Psychology, 87, 415-422.

Green, J. (1984) Effects of intrahemispheric interference on reaction times to lateral stimuli. Journal of Experimental Psychology: Human Perception and Performance, 10, 292-306.

REFERENCES

(Continued)

Green, J. (1977) Interference Between Stimulus and Response Processing
   Demands Within a Cerebral Hemisphere. Unpublished dissertation,
   University of Massachusetts.

Gross, M. M. (1972) Hemispheric specialization for processing of visually-
   presented verbal and spatial stimuli. Perception and Psychophysics, 12,
   357-363.

Gur, R. C. and Gur, R. E. (1977) Correlates of conjugate lateral eye
   movements in man. In S. Harnad, R. W. Doty, L. Goldstein, J. Jaynes, and
   G. Krauthamer, eds. Lateralization in the Nervous System, New York:
   Academic Press.

Heister, G. and Schroeder-Heister, P. (1985) S-R compatibility effect or
   cerebral laterality effect? Comments on a controversy. Neuropsychologia,
   23, 427-430.

Heister, G. (1984) Sex differences and cognitive/motor interference with
   visual half-field stimulation. Neuropsychologia, 22, 205-214.

Hellige, J. B., Cox, P. I. and Litvac, L. (1979) Information processing in
   the cerebral hemispheres: Selective hemispheric activation and capacity
   limitations. Journal of Experimental Psychology: General, 108, 251-279.

Herron, J., ed. (1980) Neuropsychology of Left-Handedness. New York:
   Academic Press.

REFERENCES

(Continued)

Hicks, R. E. (1975) Intrahemispheric response competition between vocal and
unimanual performance in normal adult human males. Journal of Comparative
and Physiological Psychology, 89, 50-60.

Kahneman, D. (1973) Attention and Effort. Englewood Cliffs, New Jersey:
Prentice-Hall, Inc.

Kinsbourne, M. (1970) The cerebral basis of lateral asymmetries in
attention. Acta Psychologica, 33, 193-201.

Krueger, L. E. (1979) A model of unidimensional perceptual matching.
Journal of Experimental Psychology: Human Perception and Performance, 5,
277-288.

Lawrence, D. G. and Kuypers, H. G. J. M. (1968) The functional organization
of the motor system in the monkey: II. The effects of lesions of
descending brainstem pathways. Brain, 91, 15-36.

Leiber, L. (1976) Lexical decisions in the right and left cerebral
hemispheres. Brain and Language, 3, 443-50.

Levy, J., Heller, W., Banich, M. T., and Burton, L. A. (1983) Are variations
among right-handed individuals in perceptual asymmetries caused by
characteristic arousal differences between hemispheres? Journal of
Experimental Psychology: Human Perception and Performance, 9, 329-359.

Moray, N., ed. (1979) Mental Workload: Its Theory and Measurement. New
York: Plenum.

Moscovitch M., and Klein, D. (1976) Material-specific perceptual
interference for visual words and faces: Implications for models of
capacity limitations, attention, and laterality. Journal of Experimental
Psychology: Human Perception and Performance, 2, 401-416.

REFERENCES

(Continued)

Myers, R. E. (1962) In Mountcastle, V. B. Interhemispheric Relations and Cerebral Dominance, Baltimore: John Hopkins Press.

Norman, D. A. and Bobrow, D. G. (1975) On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Oldfield, R. C. (1971) The assessment of handedness: The Edinburgh Inventory. Neuropsychologia, 9, 97-111.

Paivio, A., Yuille, J. C. and Madigan, S. A. (1968) Concreteness, imagery, and meaningfulness values of 925 nouns. Journal of Experimental Psychology, 76 (1, Pt 2).

Posner, M. I. (1978) Chronometric Explorations of Mind. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Sergent, J. (1982) The cerebral balance of power: confrontation or cooperation? Journal of Experimental Psychology: Human Perception and Performance, 8, 253-272.

Simon, J. R., Sly, P. E., and Vilapakkam, S. (1981) Effect of compatibility of S-R mappings on reactions toward the stimulus source. Acta Psychologica, 47, 63-81.

Sperling, G. (1960) The information available in brief visual presentations. Psychological Monographs, 74 (11), whole.

Sussman, H. M. (1982) Contrastive patterns of intrahemispheric interference to verbal and spatial concurrent tasks in right-handed, left-handed, and stuttering populations. Neuropsychologia, 20, 675-684.

REFERENCES

(Continued)

Thorndike, E. L. and Lorge, I. (1944) The Teacher's Word Book of 30,000
Words. New York: Teachers College, Columbia University.

Wallace, R. J. (1971). S-R compatibility and the idea of a response code.
Journal of Experimental Psychology, 88, 354-360.

Wickens, C. D. (1980). The structure of attentional resources. In R. S.
Nickerson (Ed.), Attention and Performance VIII. Hillsdale, New Jersey:
Lawrence Erlbaum Associates, Inc.

Young, A. W. (1982) Methodological and theoretical bases of visual hemifield
studies. In J. G. Beaumont (Ed.), Divided Visual Field Studies of
Cerebral Organization, New York: Academic Press.

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APPENDICES

HANDEDNESS INVENTORY

Name _____

Please indicate your preferences in the use of hands in the following activities by checking the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, check the "Always" column for the appropriate hand. Fo tasks in which you usually use a specific hand because it is more comfortabl   ut could use the other hand, check the "Mostly" column for the appropriate ha .. For tasks in which either hand could be used without any differences in comfort or performance, check the "Either" column.

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the subject or task.

	(1) Always Left	(2) Mostly Left	(3) Either Hand	(4) Mostly Right	(5) Always Right
1 Writing					
2 Drawing					
3 Throwing					
4 Scissors					
5 Toothbrush					
6 Knife (without fork)					
7 Spoon					
8 Broom (upper hand)					
9 Striking Match (match)					
10 Opening box (lid)					
i Which foot do you prefer to kick with?					
ii Which eye do you use when using only one?					

HANDEDNESS INVENTORY (Concluded)

Did you tend to be left-handed when you were a child? _____

Are there any activities which you perform with the left hand? _____
If yes, please name them: _____

_____

_____

_____

Are there any activities which you can perform well with either hand? _____
If yes, please name them: _____

_____

_____

_____

Indicate the preferred hand used by each of the following relatives. Mark "R" for right-handed, "L" for left-handed, and "A" for ambidextrous. Mark "?" if you do not know.

_____ Father   _____ Paternal Grandfather

_____ Mother   _____ Paternal Grandmother

_____ Brothers; How many? _____   _____ Maternal Grandfather

_____ Sisters; How many? _____   _____ Maternal Grandmother

APPENDIX B-1

Experiment 13A: Median Reaction Time (msec) for Individual Subjects

| | Left | | | | | | Right | | | | | |
| | Match | | | Mismatch | | | Match | | | Mismatch | | |
Subject	L	R	C	L	R	C	L	R	C	L	R	C
Right first												
1	399	381	385	445	410	437	409	433	414	429	441	443
2	517	600	542	539	522	525	539	549	506	550	589	588
3	439	428	411	429	411	426	417	412	387	447	418	428
4	467	483	458	489	451	464	496	500	470	482	435	462
5	514	485	489	519	517	550	537	493	528	505	571	579
6	503	529	491	566	514	544	501	564	504	558	611	614
Left first												
7	516	530	496	567	549	570	385	391	396	423	463	439
8	568	489	558	560	547	559	462	454	493	478	464	494
9	460	437	453	508	479	486	437	442	449	470	496	492
10	540	510	506	607	520	575	419	391	446	446	478	450
11	474	548	493	539	456	501	492	433	437	427	414	457
12	486	502	488	546	531	522	457	457	447	465	479	460
X	490	494	481	526	492	513	463	460	456	473	488	492

Visual Field = Left, Right, or Center

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APPENDIX B-2

Experiment 13A: Percentage of Error for Individual Subjects

Hand →	Left						Right					
Stimulus Type →	Match			Mismatch			Match			Mismatch		
Visual Field →	L	R	C	L	R	C	L	R	C	L	R	C
Subject ↓												
Hand Order ↓												
Right first												
1	16.0	6.0	6.0	8.0	14.0	4.0	6.0	16.0	10.0	14.0	6.0	14.0
2	16.0	22.0	12.0	10.0	0.0	0.0	18.0	16.0	4.0	8.0	20.0	14.0
3	4.0	20.0	4.0	16.0	6.0	10.0	14.0	8.0	8.0	4.0	12.0	10.0
4	16.0	10.0	4.0	10.0	6.0	14.0	10.0	16.0	14.0	8.0	12.0	10.0
5	16.0	8.0	12.0	2.0	6.0	16.0	8.0	30.0	18.0	16.0	8.0	22.0
6	6.0	0.0	6.0	8.0	4.0	2.0	6.0	8.0	6.0	2.0	2.0	2.0
Left first												
7	6.0	4.0	12.0	2.0	4.0	6.0	8.0	2.0	6.0	4.0	14.0	16.0
8	8.0	14.0	2.0	8.0	2.0	14.0	6.0	18.0	2.0	10.0	6.0	14.0
9	8.0	14.0	8.0	20.0	8.0	12.0	16.0	10.0	10.0	8.0	16.0	14.0
10	18.0	6.0	2.0	2.0	10.0	10.0	4.0	4.0	2.0	6.0	18.0	8.0
11	4.0	22.0	10.0	16.0	4.0	8.0	14.0	16.0	8.0	2.0	0.0	14.0
12	6.0	6.0	12.0	10.0	16.0	12.0	10.0	0.0	8.0	6.0	20.0	8.0
X̄	10.3	11.0	7.5	9.3	6.7	9.0	10.0	12.0	8.0	7.3	11.2	12.2

Visual Field = Left, Right, or Center

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APPENDIX C-1

Experiment 13B: Median Reaction Time (msec) for Individual Subjects

Hand →	Left						Right					
Stimulus Type →	Match			Mismatch			Match			Mismatch		
Visual Field →	L	R	C	L	R	C	L	R	C	L	R	C
Subject ↓												
Hand Order ↓												
Right first												
1	425	420	400	461	483	466	510	570	484	505	499	559
2	532	503	496	535	538	538	529	522	522	576	570	556
3	517	509	511	528	572	539	545	583	558	610	565	597
4	434	506	476	518	523	487	521	439	503	583	543	528
5	470	496	467	553	541	557	677	670	683	843	771	1129
6	462	458	454	480	558	501	500	421	445	531	502	543
Left first												
7	555	561	512	531	537	481	454	446	430	458	464	499
8	500	615	533	605	619	605	502	497	479	536	534	532
9	651	651	592	611	586	656	584	594	524	514	524	540
10	900	819	772	857	1072	987	617	587	624	624	626	627
11	386	448	397	458	505	470	426	419	401	431	402	428
12	464	664	530	582	622	587	493	585	482	578	490	539
X̄	525	554	512	560	596	573	530	528	511	566	541	590

Visual Field = Left, Right, or Center

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Experiment 13B: Percentage of Error for
Individual Subjects

	Hand	Left						Right					
	Stimulus Type	Match			Mismatch			Match			Mismatch		
Hand Order	Subject / Visual Field	L	R	C	L	R	C	L	R	C	L	R	C
Right first	1	12.0	4.0	2.0	16.0	8.0	14.0	4.0	8.0	0.0	4.0	8.0	18.0
	2	16.0	0.0	6.0	10.0	20.0	14.0	16.0	24.0	6.0	4.0	6.0	16.0
	3	2.0	16.0	8.0	4.0	14.0	4.0	20.0	16.0	4.0	16.0	2.0	0.0
	4	12.0	16.0	16.0	12.0	14.0	12.0	18.0	8.0	6.0	2.0	20.0	8.0
	5	10.0	2.0	6.0	14.0	10.0	14.0	2.0	6.0	4.0	24.0	10.0	22.0
	6	12.0	6.0	6.0	8.0	18.0	14.0	2.0	14.0	2.0	20.0	12.0	12.0
Left first	7	10.0	14.0	6.0	12.0	14.0	14.0	10.0	2.0	8.0	8.0	18.0	18.0
	8	2.0	14.0	2.0	12.0	10.0	10.0	8.0	10.0	8.0	4.0	6.0	6.0
	9	10.0	8.0	6.0	6.0	4.0	14.0	14.0	10.0	2.0	10.0	2.0	16.0
	10	4.0	4.0	4.0	6.0	14.0	10.0	10.0	4.0	6.0	6.0	10.0	8.0
	11	12.0	16.0	6.0	2.0	14.0	4.0	14.0	22.0	2.0	4.0	2.0	8.0
	12	6.0	28.0	4.0	12.0	4.0	6.0	6.0	18.0	6.0	22.0	6.0	10.0
	X̄	9.0	10.7	6.0	9.5	12.0	10.8	10.3	11.8	4.5	10.3	8.5	11.8

Visual Field = Left, Right, or Center

APPENDIX D-1

Experiment 14: Median Reaction Time (msec)
for Individual Subjects

Subject ↓

Finger	"Go" Stimulus Type	Hand Order	Subject	Left L	Left R	Left C	Right L	Right R	Right C
Index	Match	Right first	1	358	364	359	356	348	350
			2	398	369	370	487	464	449
			3	367	361	355	371	371	379
		Left first	4	398	382	381	345	340	340
			5	367	373	359	369	359	338
			6	374	382	347	372	364	355
	Mismatch	Right first	7	408	398	404	426	427	440
			8	405	401	382	430	453	431
			9	393	366	385	373	402	383
		Left first	10	442	442	409	444	431	397
			11	599	632	654	446	473	474
			12	406	473	413	376	367	367
Middle	Match	Right first	13	375	388	366	424	421	400
			14	339	349	329	340	341	327
			15	343	326	332	341	327	340
		Left first	16	468	483	449	439	448	419
			17	425	415	395	373	373	378
			18	393	381	382	398	394	386
	Mismatch	Right first	19	433	444	416	443	470	461
			20	401	397	392	426	425	427
			21	455	457	417	482	496	462
		Left first	22	400	426	406	346	372	361
			23	385	400	400	411	418	404
			24	395	392	397	403	380	380

Visual Field = Left, Right, or Center

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APPENDIX D-2

Experiment 14: Percentage of Error for
Individual Subjects

				Left			Right		
Hand →									
Visual Field →				L	R	C	L	R	C
Finger ↓	"Go" Stimulus Type ↓	Hand Order ↓	Subject ↓						
Index	Match	Right first	1	0.0	0.0	0.0	0.0	0.0	0.0
			2	12.0	6.0	0.0	0.0	0.0	0.0
			3	0.0	0.0	0.0	2.0	0.0	4.0
		Left first	4	2.0	2.0	0.0	0.0	0.0	0.0
			5	4.0	2.0	2.0	2.0	0.0	0.0
			6	0.0	0.0	2.0	0.0	0.0	0.0
	Mismatch	Right first	7	0.0	0.0	0.0	0.0	0.0	0.0
			8	0.0	4.0	0.0	0.0	0.0	10.0
			9	2.0	0.0	2.0	2.0	6.0	6.0
		Left first	10	2.0	0.0	2.0	0.0	2.0	2.0
			11	4.0	8.0	2.0	0.0	6.0	4.0
			12	2.0	4.0	4.0	0.0	4.0	2.0
Middle	Match	Right first	13	0.0	0.0	0.0	0.0	2.0	0.0
			14	0.0	0.0	0.0	0.0	0.0	0.0
			15	0.0	0.0	0.0	0.0	0.0	0.0
		Left first	16	0.0	2.0	0.0	0.0	2.0	0.0
			17	0.0	2.0	0.0	0.0	0.0	0.0
			18	0.0	0.0	2.0	2.0	2.0	0.0
	Mismatch	Right first	19	0.0	2.0	4.0	4.0	2.0	4.0
			20	4.0	4.0	4.0	2.0	0.0	0.0
			21	0.0	2.0	0.0	0.0	0.0	0.0
		Left first	22	0.0	2.0	0.0	4.0	0.0	0.0
			23	2.0	0.0	2.0	2.0	2.0	2.0
			24	0.0	0.0	2.0	0.0	0.0	2.0
			X̄	1.4	1.7	1.2	0.9	1.2	1.6

Visual Field = Left, Right, or Center

APPENDIX E-1

Experiment 15: Median Reaction Time (msec) for Individual Subjects

Hand →		Left							Right					
Stimulus Type →		Match			Mismatch			Match			Mismatch		
Visual Field →		L	R	C	L	R	C	L	R	C	L	R	C
RA↓ Hand Order↓ Subject↓														
1	Right first 1	504	517	472	534	539	566	551	591	551	600	610	612
	2	386	375	361	398	445	386	409	466	416	460	442	440
	3	520	457	497	524	508	519	556	556	534	527	554	568
	4	600	511	488	479	553	525	543	617	503	576	586	612
	5	399	374	394	436	439	442	379	382	373	408	407	426
	6	580	605	576	612	579	586	670	666	646	639	634	663
	Left first 7	521	460	514	475	507	539	417	429	370	450	452	474
	8	559	616	528	549	529	554	451	426	405	464	524	476
	9	731	735	747	776	712	749	539	536	498	521	541	541
	10	601	538	525	595	555	578	513	495	470	468	536	498
	11	611	643	554	625	567	626	600	535	579	522	553	562
	12	588	633	580	612	541	606	582	521	553	490	569	542
	X̄	550	539	520	551	540	556	518	518	492	510	534	535

RA = Response Assignment

Visual Field = Left, Right, or Center

APPENDIX E-1 (Concluded)

Experiment 15: Median Reaction Time (msec)

for Individual Subjects

Hand →							2						
		Left						Right					
Stimulus Type →		Match			Mismatch			Match			Mismatch		
Visual Field →	Subject ↓	L	R	C	L	R	C	L	R	C	L	R	C
RA ↓ Hand Order ↓													
2 Right first	13	488	529	519	487	532	526	633	699	634	669	646	665
	14	543	475	516	517	536	475	518	608	518	612	510	545
	15	565	534	535	526	557	547	539	540	574	596	577	633
	16	639	547	562	581	676	593	636	704	638	642	675	642
	17	383	408	370	419	400	414	439	376	431	432	466	509
	18	518	489	475	495	576	567	537	549	538	572	532	566
Left first	19	488	509	498	560	593	593	475	491	470	538	496	530
	20	820	761	740	758	823	800	643	665	651	739	727	741
	21	521	566	509	588	583	610	599	627	550	616	599	582
	22	840	920	875	1016	933	1044	621	609	576	634	655	631
	23	583	546	577	545	620	678	581	575	645	527	581	562
	24	540	558	569	587	549	555	482	453	489	489	482	522
	X̄	577	570	562	594	615	617	559	575	560	589	579	594

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX E-2

Experiment 15: Percentage of Error for Individual Subjects

Hand →		Left						Right					
Stimulus Type →		Match			Mismatch			Match			Mismatch		
Visual Field →		L	R	C	L	R	C	L	R	C	L	R	C
RA ↓ Hand Order ↓ Subject ↓													
1 Right first	1	14.0	10.0	6.0	4.0	8.0	14.0	18.0	18.0	2.0	10.0	2.0	10.0
	2	2.0	2.0	2.0	2.0	22.0	12.0	2.0	16.0	8.0	14.0	0.0	6.0
	3	14.0	4.0	4.0	6.0	6.0	14.0	14.0	16.0	2.0	2.0	14.0	8.0
	4	24.0	4.0	2.0	0.0	16.0	10.0	18.0	8.0	2.0	10.0	8.0	16.0
	5	6.0	10.0	4.0	10.0	2.0	14.0	8.0	14.0	2.0	14.0	8.0	10.0
	6	10.0	10.0	10.0	14.0	4.0	4.0	16.0	14.0	4.0	0.0	10.0	10.0
Left first	7	26.0	0.0	8.0	4.0	12.0	10.0	12.0	20.0	12.0	12.0	12.0	6.0
	8	20.0	24.0	8.0	12.0	2.0	0.0	10.0	4.0	8.0	4.0	18.0	14.0
	9	4.0	4.0	4.0	2.0	6.0	6.0	10.0	6.0	2.0	6.0	2.0	2.0
	10	30.0	2.0	6.0	6.0	0.0	6.0	24.0	6.0	4.0	4.0	8.0	4.0
	11	10.0	10.0	4.0	10.0	4.0	10.0	12.0	4.0	8.0	0.0	12.0	6.0
	12	6.0	8.0	0.0	6.0	8.0	6.0	8.0	8.0	4.0	8.0	10.0	6.0
	$\overline{X}$	13.8	7.3	4.8	6.3	7.5	8.8	12.7	11.2	4.8	7.0	8.7	8.2

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX E-2 (Concluded)

Experiment 15: Percentage of Error for
Individual Subjects

Hand →															
Stimulus Type →				Left							Right				
Visual Field →			Match			Mismatch			Match			Mismatch				
			L	R	C	L	R	C	L	R	C	L	R	C		
RA ↓	Hand Order ↓ Subject ↓															
2	Right first	13	4.0	10.0	8.0	6.0	8.0	6.0	8.0	8.0	0.0	2.0	2.0	4.0		
		14	4.0	4.0	6.0	2.0	10.0	14.0	4.0	14.0	4.0	12.0	4.0	6.0		
		15	8.0	10.0	8.0	12.0	24.0	4.0	16.0	14.0	12.0	6.0	6.0	6.0		
		16	6.0	0.0	0.0	2.0	12.0	10.0	2.0	8.0	2.0	14.0	4.0	16.0		
		17	12.0	16.0	2.0	2.0	4.0	6.0	12.0	4.0	6.0	0.0	8.0	6.0		
		18	8.0	10.0	4.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	6.0	6.0		
	Left first	19	10.0	8.0	6.0	4.0	26.0	12.0	10.0	14.0	2.0	12.0	4.0	14.0		
		20	4.0	12.0	8.0	0.0	14.0	8.0	10.0	10.0	4.0	12.0	8.0	10.0		
		21	16.0	6.0	12.0	2.0	12.0	6.0	0.0	16.0	4.0	14.0	4.0	18.0		
		22	2.0	6.0	12.0	14.0	4.0	14.0	6.0	0.0	2.0	6.0	18.0	14.0		
		23	6.0	14.0	6.0	2.0	2.0	6.0	16.0	4.0	14.0	6.0	12.0	0.0		
		24	8.0	16.0	8.0	8.0	8.0	8.8	18.0	6.0	8.0	2.0	20.0	10.0		
		$\overline{X}$	7.3	9.3	6.7	5.0	10.8	8.3	9.0	8.8	5.5	7.8	8.0	9.2		

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX F-1

Experiment 16: Median Reaction Time (msec)
for Individual Subjects

| | | Left | | | | | | Right | | | | | |
| | | Match | | | Mismatch | | | Match | | | Mismatch | | |
Hand → / Stimulus Type → / Visual Field →

Subject	L	R	C	L	R	C	L	R	C	L	R	C
Right first												
1	582	488	533	514	558	540	633	599	604	565	611	598
2	413	555	516	541	541	537	569	570	542	562	607	571
3	490	532	467	443	461	483	549	571	512	462	503	513
4	508	514	522	543	550	571	508	508	485	527	520	548
5	547	522	527	537	524	558	533	544	508	571	582	579
6	439	452	426	477	474	490	417	456	435	515	520	523
Left first												
7	462	483	485	507	465	504	402	419	396	454	461	454
8	496	538	518	593	524	535	510	451	449	516	515	498
9	656	659	617	660	651	632	414	457	454	494	502	503
10	647	684	677	617	613	681	531	530	513	506	599	511
11	488	478	485	519	516	566	445	465	452	472	485	469
12	653	676	634	629	621	673	524	510	485	498	513	537
$\bar{X}$	532	548	534	548	542	564	503	507	486	512	535	525

RA = 1

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX F-1 (Concluded)

Experiment 16: Median Reaction Time (msec)

for Individual Subjects

Hand →	Left						Right					
Stimulus Type →	Match			Mismatch			Match			Mismatch		
Visual Field →	L	R	C	L	R	C	L	R	C	L	R	C
RA ↓ Hand Order ↓ Subject ↓												
2 Right first 13	451	417	461	495	529	521	532	555	496	597	552	602
14	474	482	454	480	476	482	635	606	599	567	600	548
15	414	419	414	435	456	423	451	459	425	425	434	420
16	515	508	534	563	597	580	589	630	637	612	626	620
17	386	386	390	496	525	510	491	447	455	491	515	531
18	431	472	458	454	502	458	493	476	484	514	486	494
Left first 19	955	934	871	826	815	850	686	719	652	599	609	559
20	606	596	556	570	580	568	540	465	486	468	514	491
21	515	500	478	532	58?	·3	474	368	393	534	519	525
22	692	663	679	746	737	2	663	556	584	530	564	509
23	773	801	7 ·	787	772	63	730	709	679	709	678	692
24	562	588	541	569	583	600	501	506	488	484	499	497
X̄	565	564	549	579	596	589	565	541	532	544	550	541

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX F-2

Experiment 16: Percentage of Error for Individual Subjects

Hand →	Left						Right					
Stimulus Type →	Match			Mismatch			Match			Mismatch		
Visual Field →	L	R	C	L	R	C	L	R	C	L	R	C
RA → 1 Hand Order ↓ Subject ↓												
Right first												
1	8.0	4.0	6.0	14.0	6.0	10.0	6.0	8.0	4.0	4.0	8.0	10.0
2	12.0	8.0	4.0	2.0	0.0	2.0	8.0	8.0	2.0	4.0	4.0	14.0
3	6.0	8.0	6.0	2.0	0.0	4.0	8.0	18.0	2.0	0.0	0.0	4.0
4	6.0	4.0	4.0	10.0	12.0	6.0	14.0	4.0	8.0	6.0	14.0	10.0
5	4.0	4.0	8.0	4.0	6.0	6.0	6.0	10.0	6.0	2.0	10.0	8.0
6	12.0	4.0	4.0	12.0	16.0	14.0	10.0	0.0	10.0	8.0	10.0	16.0
Left first												
7	6.0	4.0	4.0	4.0	0.0	12.0	6.0	0.0	0.0	6.0	14.0	10.0
8	10.0	6.0	12.0	6.0	4.0	6.0	8.0	2.0	4.0	14.0	8.0	12.0
9	8.0	4.0	6.0	6.0	4.0	10.0	4.0	6.0	8.0	4.0	16.0	6.0
10	4.0	10.0	4.0	4.0	2.0	4.0	8.0	8.0	2.0	6.0	10.0	8.0
11	4.0	12.0	8.0	10.0	2.0	8.0	6.0	6.0	14.0	6.0	12.0	8.0
12	4.0	14.0	2.0	6.0	6.0	10.0	12.0	6.0	`.2	0.0	8.0	12.0
X̄	7.0	6.8	5.7	6.7	4.8	7.7	8.0	6.	5.2	5.0	9.5	9.8

RA = Response Assignment

Visual Field = Left, Right, or Center

APPENDIX F-2 (Concluded)

Experiment 16: Percentage of Error for
Individual Subjects

Hand → 2

			Left						Right					
		Match			Mismatch			Match			Mismatch			
RA → Hand Order → / Subject →		L	R	C	L	R	C	L	R	C	L	R	C	
Right first	13	10.0	4.0	10.0	10.0	12.0	8.0	10.0	6.0	6.0	6.0	552	10.0	
	14	6.0	10.0	8.0	4.0	4.0	6.0	8.0	20.0	2.0	6.0	600	4.0	
	15	6.0	12.0	10.0	16.0	12.0	6.0	12.0	8.0	6.0	6.0	434	10.0	
	16	10.0	2.0	12.0	6.0	4.0	2.0	12.0	4.0	6.0	0.0	626	6.0	
	17	4.0	12.0	6.0	18.0	8.0	10.0	14.0	4.0	6.0	8.0	515	8.0	
	18	10.0	8.0	6.0	12.0	2.0	2.0	2.0	2.0	14.0	8.0	486	4.0	
Left first	19	16.0	6.0	0.0	4.0	10.0	12.0	8.0	8.0	4.0	6.0	14.0	8.0	
	20	12.0	14.0	10.0	4.0	4.0	16.0	18.0	18.0	18.0	8.0	6.0	10.0	
	21	12.0	4.0	6.0	10.0	6.0	6.0	8.0	4.0	2.0	6.0	16.0	12.0	
	22	4.0	4.0	4.0	4.0	4.0	10.0	10.0	14.0	2.0	6.0	2.0	0.0	
	23	6.0	16.0	8.0	10.0	10.0	10.0	16.0	20.0	6.0	6.0	2.0	12.0	
	24	4.0	8.0	2.0	6.0	2.0	4.0	8.0	8.0	4.0	0.0	2.0	6.0	
	X̄	8.3	8.3	4.5	7.5	8.5	8.3	8.5	10.8	6.7	6.0	6.3	7.5	

RA = Response Assignment

Visual Field = Left, Right, or Center

APPENDIX G

Concreteness-Abstractness Rating Study
for Lexical Decision Task

INTRODUCTION

The purpose of the present study was to obtain concreteness-abstractness ratings of a list of four-letter, one syllable nouns of known frequency as determined by Thorndike and Lorge (1944). The study was necessary because existing word lists which include ratings of concreteness-abstractness (Brown & Ure, 1969; Paivio, et. al., 1968) did not include sufficient numbers of four-letter nouns.

METHOD

Subjects. The subjects were 31 male and 7 female Georgia Tech undergraduates participating to receive credit in psychology courses.

Stimuli. The stimuli were 223 four-letter, one-syllable nouns selected from the Thorndike-Lorge Teacher's Word Book of 30,000 Words (1944). The stimuli were listed in a booklet with a rating scale next to each of them. The pages within the booklet were randomly ordered between subjects. One page was repeated no less than six pages later to allow computation of within-subject reliability.

Method. Subjects were tested in groups. Each subject was given a booklet with the instructions and the list of items to rate for concreteness-abstractness. The subjects were instructed to rate each word's concreteness-abstractness using a seven-point scale. Half of the subjects (Group 1) were instructed to give the most concrete words the highest number, i.e., seven; the other half (Group 2) were told to give the most abstract word the highest number. Subjects were told not to look back at items they had already rated. There was no time limit imposed on their performance.

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RESULTS

Assessment of Reliability and Validity. Rating reliability was assessed both within and between subjects, using the Pearson r. Within-subject reliability was computed by correlating, for each subject, the ratings of each item on the repeated page. The correlations averaged 0.89, with a standard deviation of 0.13.

Between-subject reliability was calculated through a split-half correlation of selected items. The subjects were divided into two groups, and the mean rating for each item within the group was calculated. The correlation was computed between the two subgroup mean scores on a subset of seventeen items from the original list. The correlation was 0.95. Both within and between subject analyses therefore suggest high reliability of ratings.

The validity of ratings was assessed by computing the correlation between the average ratings and ratings given by Paivio, et. al. (1968) and Brown and Ure (1969) for common items. The correlation between the average subject ratings and the Paivio, et. al. ratings was 0.98 for 45 common items. The correlation between the average subject ratings and the Brown and Ure ratings was 0.92 for 25 common items.

Selection of Stimulus Items. The 64 nouns having the highest concreteness rating and the 64 having the lowest concreteness rating were selected as stimulus items. Each word was used as the basis for forming a one-syllable, prounounceable nonword have all or three of the same letters. The words, their concreteness ratings, and the corresponding nonwords are shown in Appendix H.

APPENDIX H

Items Used in Lexical Decision Task

	Word	Frequency[1]	Mean Concreteness[2]	Corresponding Nonword
1.	SOUL	99	1.42	LOUS
2.	LOVE	99	1.45	VOLE
3.	HOPE	99	1.50	POHE
4.	LUCK	46	1.55	CULK
5.	FATE	50	1.58	TAFE
6.	FEAR	99	1.79	RAFE
7.	CARE	99	1.87	CRAE
8.	MOOD	27	2.00	DOIM*[3]
9.	NEED	99	2.11	DEEN
10.	TIME	99	2.36	MOTE*
11.	SAKE	50	2.16	SKAE
12.	RISK	40	2.32	SKIR
13.	MIND	99	2.39	NIMD
14.	ODDS	10	2.45	DODS
15.	EASE	50	2.45	AESE
16.	LIFE	99	2.50	EILF
17.	LACK	50	2.50	CLAK
18.	MYTH	8	2.55	HYMT
19.	FAME	50	2.55	MAFE
20.	GLEE	9	2.58	LEGE
21.	CALM	50	2.61	LAMC
22.	GOAL	21	2.66	LOAG
23.	GAIN	99	2.71	NAIG
24.	RATE	99	2.82	TROE*
25.	SORT	99	2.92	ROST
26.	OATH	18	3.00	HOAT
27.	JEST	20	3.00	STEJ
28.	HINT	9	3.00	NITH
29.	MODE	23	3.03	OEMD
30.	RULE	99	3.05	LEUR
31.	PLEA	10	3.08	LAPE
32.	EAST	99	3.18	STEA
33.	HARM	50	3.21	MAHR
34.	ROLE	11	3.32	ORLE
35.	PLAN	99	3.34	NALP
36.	RUIN	50	3.34	NUIR
37.	FUSS	11	3.34	SUFS
38.	DIET	27	3.39	TIED
39.	WEST	99	3.39	TEWS
40.	PACE	50	3.45	CEIP*
41.	HOUR	99	3.45	HURE
42.	SPAN	13	3.50	NASP
43.	REST	99	3.50	ERST
44.	TYPE	99	3.53	PYTE
45.	TASK	50	3.55	KEST*
46.	RANK	50	3.58	NIRK*

Items Used in Lexical Decision Task
(continued)

	Word	Frequency[1]	Mean Concreteness[2]	Corresponding Nonword
47.	BULK	20	3.61	KULB
48.	SIZE	99	3.61	ZISE
49.	COST	99	3.63	STEC*
50.	WEEK	99	3.66	EWKE
51.	FACT	99	3.66	CAFT
52.	BOND	50	3.68	BUND*
53.	YEAR	99	3.71	YARE
54.	TERM	50	3.74	REMT
55.	DOSE	8	3.82	SADE*
56.	CODE	21	3.92	DOCE
57.	FOLK	50	3.95	KLOF
58.	SALE	50	3.97	LASE
59.	VIEW	99	4.00	WUVE
60.	POLL	17	4.03	LOLP
61.	FLAW	6	4.03	WALF
62.	CURE	46	4.05	RUCE
63.	VICE	34	4.05	CEIV
64.	WORK	99	4.08	ROWK
65.	TOWN	99	6.13	TWON
66.	LAND	99	6.24	NALD
67.	RACK	29	6.24	KARC
68.	CASH	46	6.29	CHIS*
69.	LAWN	37	6.32	WALN
70.	TOMB	22	6.39	BOMT
71.	SEAT	99	6.39	TASE
72.	SCAR	17	6.42	CRES*
73.	DUST	50	6.45	SUDT
74.	TOOL	40	6.45	LOTE*
75.	TUBE	32	6.45	BUTE
76.	BOWL	50	6.45	WOLB
77.	POLE	50	6.47	PLOE
78.	FIRE	99	6.50	RIFE
79.	VEIN	30	6.50	NIVE
80.	TAIL	50	6.50	ALIE*
81.	MONK	20	6.50	KIME*
82.	FORT	43	6.53	TORF
83.	ROOT	50	6.55	OORT
84.	WING	99	6.58	NIWG
85.	SEED	50	6.61	DESE
86.	PEAR	21	6.63	PREA
87.	BEEF	20	6.66	FEBE
88.	ROOF	99	6.66	RAFE*
89.	HORN	50	6.68	OHRN
90.	DIRT	21	6.68	TRID
91.	PLUM	23	6.68	MULP
92.	HARP	20	6.68	PRAH

Items Used in Lexical Decision Task
(concluded)

	Word	Frequency[1]	Mean Concreteness[2]	Corresponding Nonword
93.	PAIL	16	6.71	LAIP
94.	COIN	50	6.71	NOIC
95.	SALT	99	6.74	LATS
96.	VEST	21	6.74	STEV
97.	TWIG	22	6.74	GWIT
98.	WOOD	99	6.76	DWOE*
99.	LEAF	27	6.76	LAFE
1C0.	GOLD	99	6.79	DOLG
101.	PIPE	50	6.79	EIPP
102.	RAIN	99	6.79	AIRN
103.	OVEN	29	6.79	VONE
104.	ROBE	31	6.82	BROE
105.	DESK	50	6.82	SKED
106.	POND	30	6.84	DONP
107.	LAKE	99	6.84	ILIE*
108.	MOSS	22	6.84	SIMS*
109.	VINE	38	6.84	NIVE
110.	NOSE	99	6.84	SONE
111.	CANE	19	6.87	NACE
112.	MULE	29	6.89	LUME
113.	SAND	50	6.89	NADS
114.	TENT	50	6.92	ENTT
115.	MILK	99	6.92	KLIM
116.	FLAG	50	6.92	GLAF
117.	TIRE	99	6.92	RETE
118.	GIRL	99	6.95	LIRG
119.	NAIL	50	6.95	NULE*
120.	ROPE	50	6.95	ORPE
121.	SHIP	99	6.95	PHIS
122.	DOVE	19	6.97	VODE
123.	FORK	31	6.97	FROK
124.	TREE	99	6.97	REET
125.	FOOT	99	6.97	TOOF
126.	HAND	99	6.97	NIHD*
127.	LION	50	7.00	NOIL
128.	FROG	25	7.00	GROT

Items 1-64 are categorized "concrete"; Items 65-128 are "abstract".

Average Concreteness Rating for "Concrete" Words = 6.7
Average Frequency Rating for "Concrete" Words = 54.1 per million

Average Concreteness Rating for "Abstract" Words = 3.0
Average Frequency Rating for "Abstract" Words = 59.4 per million

[1]According to Thorndike and Lorge (1944)
[2]The higher the value, the higher the perceived concreteness.   Maximum = 7.
[3]One vowel changed from word.

APPENDIX I-1

Experiment 17: Median Reaction Time (msec) for Individual Subjects

Horizontal Stimulus Orientation

| Hand → | | Left | | | | | | Right | | | | | |
| Stimulus Type → | | Concrete | | Abstract | | Nonword | | Concrete | | Abstract | | Nonword | |
Visual Field →	Subject	L	R	L	R	L	R	L	R	L	R	L	R
RA↓ 1 Hand Order↓ Left first	1	826	852	1068	766	1226	1281	1488	1468	1971	1542	2252	2408
	2	1244	1007	1046	1001	1431	1215	1003	962	1084	1054	1289	1122
	3	1047	903	937	1149	1202	1021	801	734	876	710	812	833
	4	737	668	756	648	833	713	651	559	676	578	676	741
Right first	5	736	695	748	741	778	780	1030	838	985	887	864	927
	6	793	773	822	749	861	826	969	1018	1038	912	1122	1094
	7	617	594	581	579	660	650	646	626	594	608	636	621
	8	631	561	580	565	624	644	721	733	744	651	815	773
2 Left first	9	657	572	653	627	791	756	652	542	620	590	686	636
	10	706	608	833	621	835	736	727	577	995	636	911	728
	11	806	797	803	719	1074	944	684	792	676	808	1187	1068
	12	711	742	763	727	919	870	853	867	849	845	911	914
Right first	13	766	920	874	854	921	936	1157	1157	1229	1145	1330	1220
	14	678	599	749	576	750	730	865	744	878	684	859	854
	15	1008	1006	1150	986	1065	1079	1769	1642	1752	1689	1848	1746
	16	955	963	1024	887	857	959	805	776	805	901	941	885
	X̄	807	766	837	762	927	884	926	877	986	890	1071	1036

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX I-1 (Concluded)

Experiment 17: Median Reaction Time (msec)
for Individual Subjects

Vertical Stimulus Orientation

Hand →			Left						Right					
Stimulus Type →			Concrete		Abstract		Nonword		Concrete		Abstract		Nonword	
Visual Field →			L	R	L	R	L	R	L	R	L	R	L	R
RA ↓	Hand Order	Subject ↓												
1	Left first	17	607	592	572	526	655	674	574	574	581	566	686	704
		18	900	846	866	946	1295	1267	697	661	726	648	788	924
		19	714	664	706	731	810	809	660	629	691	607	756	759
		20	694	668	630	595	661	657	880	815	926	883	931	953
	Right first	21	897	796	915	918	1178	1113	761	810	865	744	1265	1165
		22	830	846	789	961	959	1000	863	832	807	863	1177	1129
		23	765	891	797	856	1299	1232	881	1034	979	1032	1694	1357
		24	1096	986	1079	971	1312	1372	995	908	1058	881	1475	1367
2	Left first	25	728	728	743	684	937	833	924	704	837	678	979	982
		26	1120	1032	1308	1075	1916	1682	1272	1066	1392	1162	1893	1734
		27	671	578	642	619	767	852	656	703	704	681	705	737
		28	731	782	772	696	1063	1048	802	726	847	755	910	833
	Right first	29	905	696	814	712	1116	1055	682	666	727	672	778	739
		30	752	619	792	680	826	870	771	999	874	818	1404	1380
		31	582	563	590	555	585	626	760	676	802	717	918	889
		32	862	786	844	758	1009	1025	1300	1157	1308	1100	1391	1307
		X̄	803	755	804	768	1024	1007	842	810	883	800	1109	1060

RA = Response Assignment

Visual Field = Left, Right, or Center

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Experiment 17: Percentage of Error for Individual Subjects

Horizontal Stimulus Orientation

| Hand → | | Hand 1 / Hand 2 | | | | | | | | | | | |
| Stimulus Type → | | Left Concrete | | Left Abstract | | Left Nonword | | Right Concrete | | Right Abstract | | Right Nonword | |
Visual Field → Subject / RA →		L	R	L	R	L	R	L	R	L	R	L	R
Left first	1	18.8	6.3	28.1	9.4	37.5	21.9	6.3	6.3	40.6	3.1	26.6	14.1
	2	15.6	6.3	9.4	6.3	15.6	10.9	6.3	9.4	15.6	12.5	14.1	12.5
	3	28.1	9.4	31.3	9.4	14.1	15.6	34.4	3.1	28.1	12.5	10.9	14.1
	4	12.5	9.4	9.4	0.0	20.3	4.7	15.6	0.0	6.3	1.1	12.5	14.1
Right first	5	28.1	15.6	31.3	18.8	34.4	21.9	9.4	18.8	40.6	9.4	34.4	14.1
	6	28.1	18.8	40.6	0.0	31.3	15.6	28.1	3.1	34.4	6.3	32.8	15.6
	7	12.5	9.4	28.1	9.4	20.3	25.0	12.5	12.5	12.5	21.9	20.3	25.0
	8	15.6	12.5	25.0	6.3	3.1	7.8	12.5	6.3	31.3	9.4	3.1	12.5
Left first	9	21.9	9.4	6.3	15.6	29.7	17.2	12.5	12.5	18.8	9.4	14.1	14.1
	10	15.6	0.0	15.6	6.3	23.4	12.5	21.9	6.3	34.4	6.3	28.1	7.8
	11	3.1	6.3	12.5	6.3	29.7	20.3	0.0	6.3	18.8	12.5	17.2	12.5
	12	15.6	3.1	15.6	3.1	23.4	17.2	15.6	0.0	21.9	3.1	18.8	6.3
Right first	13	9.4	3.1	9.4	12.5	6.3	6.3	9.4	9.4	15.6	6.3	12.5	14.1
	14	31.3	9.4	25.0	18.8	10.9	12.5	25.0	9.4	4ʹ	15.6	17.2	12.5
	15	3.1	3.1	9.4	0.0	7.8	4.7	3.1	0.0		6.3	14.1	10.9
	16	15.6	9.4	18.8	12.5	6.2	4.7	15.6	0.	.3	9.4	17.2	15.6
X̄		19.7	8.4	17.2	8.2	19.6	13.7	23.8	9.1	14.3	6.5	18.4	13.5

RA = Response Assignment

Visual Field = Left, Right, or Center

APPENDIX I-2 (Concluded)

Experiment 17: Percentage of Error for
Individual Subjects

Vertical Stimulus Orientation

Hand →			Left						Right					
Stimulus Type →			Concrete		Abstract		Nonword		Concrete		Abstract		Nonword	
Visual Field →			L	R	L	R	L	R	L	R	L	R	L	R
RA → Subject →	Hand Order													
1	Left first	17	18.8	12.5	15.6	21.9	15.6	10.9	9.4	6.3	0.0	12.5	6.3	9.4
		18	15.6	6.3	18.8	12.5	14.1	10.9	9.4	3.1	15.6	15.6	6.3	14.1
		19	0.0	12.5	15.6	25.0	9.4	10.9	12.5	6.3	12.5	21.9	1.6	7.8
		20	3.1	12.5	28.1	18.8	21.9	14.1	9.4	12.5	21.9	15.6	9.4	9.4
	Right first	21	0.0	21.9	21.9	25.0	9.4	7.8	9.4	18.8	12.5	25.0	18.8	21.9
		22	3.1	12.5	9.4	21.9	6.3	7.8	6.3	9.4	6.3	25.0	17.2	26.6
		23	15.6	18.8	9.4	21.9	15.6	10.9	25.0	28.1	15.6	12.5	25.0	15.6
		24	9.4	0.0	18.8	3.1	15.6	12.5	31.3	3.1	28.1	12.5	21.9	17.2
2	Left first	25	9.4	3.1	9.4	15.6	20.3	4.7	3.1	3.1	12.5	6.3	28.1	14.1
		26	6.3	3.1	15.6	15.6	12.5	18.8	6.3	9.4	15.6	12.5	12.5	12.5
		27	21.9	15.6	6.3	3.1	14.1	10.9	3.1	6.3	21.9	9.4	20.3	18.8
		28	18.8	6.3	18.8	18.8	9.4	17.2	6.3	6.3	9.4	6.3	4.7	7.8
	Right first	29	12.5	9.4	3.1	9.4	20.3	21.9	6.3	6.3	18.8	6.3	21.9	10.9
		30	9.4	12.5	9.4	12.5	12.5	6.3	9.4	9.4	12.5	21.9	12.5	14.1
		31	12.5	12.5	12.5	18.8	10.9	6.3	12.5	3.1	9.4	18.8	7.8	4.7
		32	12.5	12.5	21.9	12.5	23.4	15.6	18.8	12.5	28.1	12.5	25.0	18.8
	$\overline{X}$		14.7	16.0	10.6	10.8	14.5	11.7	15.0	14.7	11.2	9.0	15.0	14.0

RA = Response Assignment

Visual Field = Left, Right, or Center

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APPENDIX J

Experiment 17: Median Reaction Time (RT, msec) and Percentage of Error (% Err) for Omitted Subjects.

Horizontal Stimulus Orientation

| | | | | Abstract Word | | | | Concrete Word | | | | Nonword | | | |
| | | | | Left | | Right | | Left | | Right | | Left | | Right | |
RA^1	Hand Order	Subject		RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err
1	Right	1		717	41	574	16	706	50	584	16	801	39	732	55
1	Right	2		1033	25	842	19	1045	28	824	19	1101	52	1140	28
1	Right	3		590	31	604	13	594	25	635	22	620	34	587	22
2	Right	4		768	41	583	3	811	34	573	6	793	26	685	13
2	Left	5		893	38	705	6	962	41	727	16	928	33	852	41
2	Left	6		1050	66	991	19	981	59	1021	22	890	30	972	17
2	Left	7		1502	41	1362	16	1501	44	1329	16	2194	30	1975	22
2	Left	8		1646	34	1361	6	1429	16	1175	6	1799	44	1623	34

RA^1 = Response Assignment

APPENDIX J (Concluded)

Experiment 17: Median Reaction Time (RT, msec) and Percentage of Error (% Err) for Omitted Subjects.

Vertical Stimulus Orientation

| Stimulus Type | | | Abstract Word | | | | Concrete Word | | | | Nonword | | | |
| Visual Field | | | Left | | Right | | Left | | Right | | Left | | Right | |
RA[1]	Hand Order	Subject	RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err	RT	%Err
1	Right	9	1171	31	1068	25	1114	28	1169	25	1270	34	1133	16
1	Right	10	1093	22	996	41	1000	34	906	22	1511	25	1436	31
2	Right	11	623	44	689	25	578	25	660	31	1037	19	871	17
2	Right	12	785	38	740	47	906	47	943	41	1253	33	1033	33
2	Right	13	766	28	702	16	773	22	704	3	812	36	908	16
2	Right	14	1159	16	1325	34	1084	19	1004	41	1528	22	1547	16
2	Right	15	1051	28	799	25	936	19	786	16	1168	30	1061	77
2	Right	16	858	28	800	22	748	16	692	9	1119	33	986	22
1	Left	17	1116	31	1120	56	947	34	1365	25	1605	28	1219	25
2	Left	18	1020	25	877	25	864	25	896	25	1138	14	1136	20

RA[1] = Response Assignment

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